TEMPORAL BONE VARIATION IN AUSTRALIAN ABORIGINES AND OTHER MODERN POPULATIONS: IMPLICATIONS FOR THE ORIGIN OF MODERN HUMANS.

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ABSTRACT

The origin of the Australian aborigine has important bearing on the origin(s) of all modern humans. Multiregionalists cite the apparent morphological similarities between modern Australians and S.E. Asian *Homo erectus* in support of the view that modern humans in Africa, Europe and Asia arose from mid-Pleistocene forebears in their respective regions.

The temporal bone is unique in Asian *H.erectus*. This study focuses on temporal bone variation in 11 modern human populations, and investigates (i) interdependence among temporal bone variables and between temporal and non-temporal variables, and (ii) whether Australians are distinctive in temporal bone morphology from other modern populations in a way which supports the claim of continuity with S.E. Asian *H.erectus*.

The main findings from the univariate and multivariate analyses undertaken in this study are as follows: Modern populations can be discriminated by temporal variables alone. This discrimination is almost as effective as that based on a wider selection of cranial variables and is not improved by size-adjustment of the temporal variables. Among the temporal features found to be characteristic of Australians, a long, thick, acutely angled mastoid contributes most to their discrimination from all other modern populations; a thick tympanic lateral rim is also important in distinguishing them from all but Eskimos.

Of the modern populations considered, Australians have one of the most distinctive temporal bones and show greater similarity to Africans than to Europeans (Poundbury) or Chinese. Only Eskimo temporal features, however, can be regarded as remarkably different from those of all other modern populations. Australians show greater resemblance in the temporal region to other modern humans than to Asian *H.erectus*, and in no one temporal feature are they found to be the most similar of modern human populations to *H.erectus*. These findings offer no support for the Multiregional interpretation of the evolution of anatomically modern humans.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLES IN CHAPTERS 4-8

TABLES IN APPENDIX

LIST OF CHARTS AND ILLUSTRATIONS

LIST OF PLATES

CHAPTER 1. INTRODUCTION

As the palaeontologist and philosopher Teilhard de Chardin perceived, we cannot get to the real beginning of anything; embryos are never fossilised, whether they be of an individual, a species, a language or an idea. Even so, we can reduce to a minimum the radius of uncertainty within which lies hidden the point of origin we seek by analysing the radiation which spreads out from it (Teilhard de Chardin 1956:64,65).

Our understanding of the emergence of anatomically modern humans is a dynamic process. Any hypothesis proposed needs continually to be reassessed and refined as new information emerges in related fields of research. To explain with certainty "where" and "when" modern humans originated would require a hominid fossil record which is adequately representative temporally and regionally, a totally reliable dating method applicable to the relevant time span and universal agreement as to a precise, unambiguous definition of "modern humans". In the absence of all three, the question of the origin of modern humans continues to be as controversial as it is intriguing.

In the last decade particularly, numerous hypotheses have been proposed to explain the origin of modern humans. Most have been modifications or extensions of one or other of the two most extreme and opposing hypotheses, the Out of Africa and the Multiregional hypotheses. Both models acknowledge that *H.erectus* dispersed from Africa into different regions, reaching eastern Asia by 0.7-1 million years ago. According to the Multiregional model, *H.erectus* then diversified into morphologically distinct regional populations, each of which evolved progressively towards anatomically modern *H.sapiens*. The Out of Africa model, however, proposes a single origin of modern humans about 200,000 years ago in Africa, expansion by 100,000 years ago to the rest of the Old World, replacement of the indigenous pre-modern populations with little or no genetic contact, and the subsequent development of genetic and morphological regional variation in modern human populations. According to this view, the development of modern regional characteristics is recent. By contrast, the Multiregional

model posits an ancient establishment of regional variation and argues that modern regional characteristics can be traced back to the *H.erectus* of the region.

How the origin of Australian Aborigines in particular fits into the story of modern human origins remains one of the most puzzling aspects, and its resolution must have important implications for the total evolutionary picture. Morphological continuity in eastern Asia has been proposed by multiregionalists as the strongest evidence for the Multiregional hypothesis, especially in the sequence from Javan *H.erectus* to modern Australian Aborigines. If confirmed, this would contradict the Out of Africa hypothesis which predicts that the Australians should have greater resemblance to other modern humans and archaic Africans than to the regional precursor.

Although numerous studies have investigated various descriptive or quantitative features as possible indicators of continuity in eastern Asia, few have included temporal bone features, despite the fact that the temporal region was regarded by Weidenreich and Santa Luca as distinctive in Asian *H.erectus*.

This study investigates temporal bone anatomy in modern humans. In the analysis of temporal bone variation within and between modern human populations, evidence is sought which might distinguish Australians from other modern humans and indicate a morphological link between modern Australians and Javan *H.erectus* consistent with continuity in Australasia.

CHAPTER 2. MODERN HUMAN ORIGINS: A REVIEW OF THE RECENT LITERATURE

2.1 TWO EXTREME MODELS

The debate over modern human origins came into sharp focus in the mid-eighties with the formulation of two opposing and apparently irreconcilable hypotheses.

OUT OF AFRICA REPLACEMENT MODEL: The view that modern humans originated in African began to take shape in the 1960s with the finding in Africa of hominid fossils which some considered to be morphologically more eligible as modern human ancestors than the comparatively highly specialised Asian *H.erectus*. This interpretation was strengthened when absolute dating revealed the comparative antiquity of associated African archaeological material (Aiello 1993:75).

According to the African Replacement hypothesis, the origin of modern humans was a unique, relatively recent event (100-200 ka ago), limited to one region, Africa. From there modern humans dispersed to Eurasia, replacing pre-modern populations with little if any hybridization. Regional characteristics subsequently evolved locally in the populations of early modern *H.sapiens* distributed from Africa. Consequently, modern humans from different non-African regions should have closer (genetically-based) resemblance to each other and to African archaic *H.sapiens* than to pre-modern *Homo* in their own regions (Stringer & Andrews 1988:1267,1268; Stringer 1989b:67,90; 1990a:68; 1993a:179,180).

MULTIREGIONAL CONTINUITY MODEL: Weidenreich first drew attention to 2 possible regional evolutionary sequences in eastern Asia from Chinese *H.erectus* to modern Chinese and from Javan *H.erectus* to modern Australians (Weidenreich 1943:248, 252-254, 1945:21,30). Coon expanded the idea of regional morphological continuity to all modern humans but argued that regional differentiation depends on genetic isolation and involves differing evolutionary rates (Coon 1962:37).

Developing the concept of regional continuity, the Multiregional hypothesis sees the origin of modern humans as neither recent nor confined to Africa. Rather, modern humans evolved gradually from local mid-Pleistocene ancestors in all major regions of the Old World,--- Europe, Asia as well as

Africa. Such an evolutionary process involved an ancient establishment of regional characteristics, maintenance of regional differences by a balance of gene exchange, selection and drift, as well as sufficient gene flow between contemporary populations to maintain humans as a single species (Wolpoff,Wu & Thorne 1984:417-419,447,463-471; Wolpoff 1985:360,361,463; 1989a:84,97,98; 1994:38,39; Frayer et al. 1993:17). Wolpoff now regards *H.erectus* as an early version of *H.sapiens* and not as a separate species (Wolpoff 1994:39).

Perhaps the most fundamentally irreconcilable aspect of these 2 models is whether or not the emergence of modern humans was an event unique in place and time, or whether it happened in at least 3 main centres throughout the world and not necessarily simultaneously. Which model best accounts for the evolution of new species and subspecies in non-humans? Groves (1992:153-160) and Gould (1994:24-28) emphasise the fact that far from Multiregionalism being the orthodox explanation for the origin of new species of animals in general, it is contrary to all standard views of evolution. Why should widespread populations, being in different environments and subject to different selection pressures evolve along the same pathway? In a study of the evolution of a number of mammals, Groves found no convincing case of regional continuity. Rather, replacement of one species (or subspecies) by another is the usual occurrence, where "replacement" need not be by a dramatic conflict but by a slightly greater efficiency in exploiting resources (Groves 1992:158,159). Therefore, in proposing Multiregionalism as the explanation for the origin of modern humans, it should be acknowledged as the exception to the rule (Gould 1994:28; Groves 1992:153).

Modified versions quickly followed the formulation of the extreme models. For example:

AFRICAN HYBRIDIZATION MODEL: Modern humans originated in Africa but during their dispersal from Africa a complex hybridization and replacement process occurred between migrating and indigenous populations, to varying degrees in different regions. (Brauer 1984:158,160,162; 1989:148,149; 1992a:95; 1992b:401,402,409; Brauer & Rimbach 1990:789,806).

ASSIMILATION MODEL: Modern humans originated in Africa, but it was through gene flow rather than population migration

or replacement that the modern morphology spread throughout Eurasia. The model accepts that the emergence of modern humans may not have proceeded uniformly in that in some regions genetic continuity may have been involved to some extent (Smith et al.1989a:58-62; 1989b:190; Smith 1993:234,244,245; 1992:153; Stringer 1990a:68; Trinkhaus 1992:40,41).

Data of possible significance in answering the question of modern human origins continue to accumulate in many fields besides palaeontology and archaeology. Genetic, physiological, and climatic research and increasingly reliable dating techniques may contribute important information. Arriving at a satisfactory model must involve synthesis of all relevant data.

2.2. FOSSIL EVIDENCE

Fossil chronology and morphology can provide evidence to help decide 2 issues of fundamental importance in determining the most appropriate modern human origin model:

1. Where and when did the earliest modern humans most probably exist?
2. Was there morphological continuity consistent with genetic continuity between archaic and modern *H.sapiens* in regions outside Africa? (Aiello 1993:79).

Proponents of multiregionalism claim that modern human populations resemble their particular local predecessors in cranial morphology more than they resemble other archaic humans. For example: Modern Europeans show similarity to Neanderthals, Petralona; modern Chinese to Upper Cave Zhoukoudian, Dali, Jinniu Shan, *Sinanthropus*; recent and fossil modern Australians to Wadjak, Ngandong, Sangiran (Thorne & Wolpoff 1981:341,342,348; 1992:28,30-32; Wolpoff,Wu & Thorne 1984:411; Wolpoff 1989a:76,79,85; 1989b:139,140; 1992a:55,56; Wolpoff & Caspari 1990:394,395; Wolpoff & Thorne 1991:37,39,40; van Vark et al.1992:414,415, but excludes Neanderthals; Frayer et al.1993:16,17,41,42).

Dating methods are beginning to provide absolute chronology for the previously difficult-to-date time span of 40-300 ka ago. The earliest modern human fossils are found in South Africa (Klasies River Mouth), East Africa (Border Cave and Omo Kibish 1) and the Levant (Skhul and Qafzeh). Omo 1 may be as early as 130 ka ago; the others date between 100 and 80

ka ago. A larger and continuous sequence of modern human specimens would be more convincing of 100,000 years of continuity in Africa (Morris 1992:131-141) but meanwhile strong evidence of such continuity is the existence of human transitional fossils with morphologies intermediate between "archaic" and "modern" humans (100-190 ka ago) e.g.Florisbad, Omo Kibish 2, Eliye Springs, Jebel Irhoud (Deacon 1993:104; Grun & Stringer 1991:174-176,181-186; Howells 1993:131-133; Schwarz & Grun 1993:44-46; Stringer 1989a:242, 1989b:91,92, 1990a:72-74, 1992b:88,89, 1993a:179).

Elsewhere, transitional forms are far less clear and the further from Africa, the less likely their occurrence (Foley & Lahr 1992:527). Outside Africa and the Levant the earliest appearance of modern humans is in Australia (at least 38ka ago, possibly 50-60ka ago, but disputed), China (at least 35ka, possibly 67ka ago but disputed), Europe (45ka ago), S.E.Asia (40ka ago) (Allen et al.1988:707; Hedges et al. 1992a:155; Roberts & Jones 1991:860,864; Roberts et al.1990:153; Brown 1993:220,221; Wu 1992:376).

Foley and Lahr are among those who believe that this fossil evidence contradicts a multiregional view and is highly supportive of an African origin (Foley & Lahr 1992:527). However, as Wood (1994:521) cautions, absence of evidence of modern human fossils in a particular region before a certain time does not necessarily demonstrate that modern humans were absent in that region before that time. It may be that fossil and/or archaeological evidence exists there but simply has not been found yet, or conditions in the region may have been unsuitable for preservation of bones or artifacts.

Nevertheless, the current fossil evidence, as well as implying an earlier appearance of modern humans in Africa and the Levant than in Europe, also indicates a coexistence of Neanderthals and modern humans in the Levant for 40 ka (Grun et al.1991:231; Mercier et al.1991:737-739; Stringer & Grun 1991:702). Such late persistence of Neanderthals and the lack of clear evidence of fossils transitional between Neanderthals and the contemporaneous anatomically modern crania Skhul and Qafzeh is regarded by some as strong grounds for rejecting the multiregional model for that part of the Old World and favouring an Out of Africa model albeit with some (unknown) degree of assimilation and/or gene flow involved (Aiello

1993:81-84,89; Bilsborough 1992:186,202,218). However, in eastern Asia the fossil evidence for the earliest appearance of modern humans and the probability of continuity are far less clear than in Europe and the Levant, not least because of the comparative scarcity of both fossils and reliable dates in eastern Asia.

Aiello argues that in eastern Asia a more complex model is needed to account for current available fossil chronology (Roberts & Spooner 1992; Roberts et al.1990:153; Brooks & Wood 1990:288:289; Klein 1992:5,12; Allen 1992:(lecture); Bartstra et al.1988:325; Wu 1985:247; Wu & Wang 1985:30-32,41).

(i) Modern humans appeared in eastern Asia earlier than in Europe (67-50 ka ago in eastern Asia, 40 ka ago in Europe).

(ii) *H.erectus* persisted later in Asia than elsewhere (up to 200-50 ka ago), implying genetic isolation and probable replacement.

(iii) A temporal overlap may have existed between Hexian and Zhoukoudian *H.erectus* (230-500 ka ago) and archaic Jinniu Shan (210-300 ka ago).

(iv) Archaic *H.sapiens* existed in eastern Asia (Dali and Mapa 110-230 ka ago) contemporaneously with late archaic *H.sapiens* in Africa.

(v) The existence of continuity in eastern Asia from *H.erectus* to modern humans remains a contentious issue. Some palaeontologists cite various morphological descriptive or craniometric features as evidence of continuity. Others have concluded that features they have tested, including ones claimed to be continuity traits, offer no support for continuity in eastern Asia.

Consequently, Aiello suggests that the origin of modern humans in eastern Asia may have involved a complex pattern of continuity, hybridization and/or gene flow (from east to west as well as west to east), local selection, genetic drift and population movement involving archaic *H.sapiens* as well as modern humans (Aiello 1993:85-89). Stringer agrees that although "Out of Africa" still provides the best match with palaeontological and genetic data, in the light of recent discoveries and research a more complex version of the model is required (Stringer 1993b:8).

Lahr and Foley also suggest a more detailed and complex Model is called for, one which explains not only the origin of

modern humans but also the origins of modern human diversity (Lahr & Foley 1994:51,1992:529). They propose a MULTIPLE DISPERSAL MODEL in which they stress the importance of probable dispersals within Africa prior to migration of modern human groups to the rest of the world. The model involves a single origin in Africa, but followed by multiple dispersals from variable African populations and through different routes, e.g. a northern route through northeast Africa and the Levant and a southern route via the Arabian Peninsula. Expansions and dispersals from already differentiated colonizing populations followed and subsequent development proceeded with different amounts of gene flow and admixture, new populations superimposed on earlier groups, isolation of some populations and different rates of morphological, genetic and cultural change (Lahr & Foley 1994:55-57).

2.3. GENETIC EVIDENCE

2.3.1. NUCLEAR DNA EVIDENCE:

In the eighties, various studies based on nuclear DNA analyses indicated a major division of human populations into African and Eurasian groups, greater genetic similarity being found in Asian, European and Australasian populations compared to the more divergent and variable genetic composition of sub-Saharan African populations. The evidence was consistent with modern humans having originated in Africa and spread from there to Europe and Asia. (Wainscoat et al.1986:491,493, 1989:37,38; Lucotte 1989:44,45,1992:80; Shreeve 1991:24; Stringer 1992a:11; Bowcock et al.1991:839, 1994:455,456; Wilson & Cann 1992:27; Mountain et al.1992:122, 1993:69,80; Nei & Roychoudhury 1993:938,940). Cavelli-Sforza further found a close correspondence of his tree of modern human population relationships, based on nuclear genetic material gathered over 50 years, with his tree of language development; both indicate a recent divergence through a series of migrations beginning in Africa and spreading through Asia to Europe, the New World and the Pacific (Cavelli-Sforza 1991:72; Cavelli-Sforza et al.1993:639,645; McKie 1992:20-25).

2.3.2. MITOCHONDRIAL DNA EVIDENCE:

The strongest apparent genetic support for the Out of Africa Replacement Model came from the reported findings of

studies carried out with mitochondrial DNA (mtDNA) (Cann et al.1987:31-36). Based on the rate of mtDNA sequence evolution and the amount of sequence evolution since the ancestor lived, modern human mtDNA was reportedly traced back to Africa about 200 ka (revised to about 350 ka (Stoneking 1993:60,62; Stoneking et al.1993:84,100)). The mtDNA evidence ran counter to multiregionalism, rejecting genetic continuity between modern and archaic Eurasian human populations since genetic differences of great antiquity were not found. Rather it corroborated the view that modern humans originated in Africa, migrated to the rest of the world, replacing without hybridization the local archaic human populations. (Cann 1992:71; Cann et al.1987:31,33,35; Stoneking & Cann 1989:17,28; Stringer & Andrews 1988:1264, 1265,1267; Vigilant et al.1991:1503-1506; Wilson & Cann 1992:22,24,26).

However, flaws in the techniques and interpretations of the mtDNA analyses were pointed out (Lewin 1987:24; Maddison 1991:355; Maddison et al.1992:111,122; Templeton 1992:737, 1993:51-70; Hedges et al.1992b:737,739; Barinaga 1992:686,687; Goldman & Barton 1992:440; Wolpoff 1989a:94-96; Wolpoff & Thorne 1991:41; Eckhardt & Melton 1993:83). The resulting phylogenetic tree is considered invalid for a number of reasons: the mtDNA data was not added randomly, insufficient analysis runs were performed, an unacceptable rooting method was employed and many other more parsimonious trees exist, most of which do not imply an African origin. Some also doubt the constancy of the mtDNA mutation rate. Although the use of phylogenetic trees based on these mtDNA studies was seriously discredited as valid corroboration of the Out of Africa hypothesis, the hypothesis itself is not thereby invalidated since the fossil evidence on which it is formulated is not affected. Nor is the Multiregional view necessarily confirmed.

Nevertheless, mtDNA evidence has consistently shown that the greatest mtDNA diversity occurs within African populations and many palaeontologists interpret this to mean the African population is therefore the oldest, thereby supporting an African modern human origin (Barinaga 1992:687; Gee 1992:583; Gibbons 1992:874; Lewin 1987:23; 1989:111; Cann et al.1987:35; Stringer & Andrews 1988:1264; Stoneking & Cann 1989:22; Vigilant et al.1991:1506; Stoneking 1993:64,65). However, Wolpoff, Templeton, Relethford and Harpending dispute that

genetic diversity in a regional population necessarily reflects the age of the population since within-group variation can be affected by other factors such as population size expansion or rates of gene flow with other populations (Relethford & Harpending 1994:251; Templeton 1993:59; Wolpoff 1989a:94).

From his reanalysis of the original mtDNA sequence data used by the Wilson group, Templeton (1993:51-70) concluded that his results favour a multiregional view of modern human origins. Alternatively, when Harpending, Sherry, Rogers and Stoneking analyzed mtDNA sequences using a new method ("mismatch distribution"), their results proved to be incompatible with a strict Replacement Model, marginally compatible with Multiregionalism and best explained by a modified version of the Out of Africa hypothesis they proposed termed the WEAK GARDEN OF EDEN hypothesis (Harpending et al. 1993:484,495). Their findings suggest that ancestral modern humans dispersed from one restricted region, probably Africa, to the rest of the Old World about 100 ka ago, but the sample was too small to spread over such a large area and maintain genetic contact. They suggest that not until approximately 50 ka ago did dramatic expansion eventuate outside Africa, (possibly driven by culture), and this expansion was from the small and long-isolated daughter populations (Harpending et al.1993:493,495).

2.4. CRANIOMETRIC EVIDENCE: FOSSIL AND MODERN HUMAN VARIATION.

2.4.1 SUITABILITY OF VARIABLES: Lieberman (1995:160) has emphasised that characters used to validly test hypotheses of modern human origins must satisfy 3 criteria:

1. They must be developmentally homologous, i.e. similar because of shared ancestry and not because of adaptation to non-genetic stimuli or convergence. (See also Brace & Hunt 1990:354).

2. They must be shared-derived (synapomorphic) characters and not primitive (symplesiomorphic). (See also Groves 1995: 179,1989:283).

3. Regional variation of the characters in both living and fossil Homo must be examined.

The characters should also be rigorously defined and involve a consistent method of scoring (Lahr 1995:181).

That many characters cited in support of modern human origins models have not satisfied the 3 criteria was demonstrated by Lieberman (1995:159-197) when his test of 33 cranial, dental and mandibular characters showed that only 6 definitely satisfy the 3 criteria.

2.4.2 ARCHAIC AND MODERN HUMAN CRANIOMETRIC VARIATION

In the same study by Lieberman (1995:159-197), although 30 of the characters investigated were proposed by Frayer et al.(1993:14-42) specifically to support the Multiregional Hypothesis, Lieberman concluded that 5 of the 6 valid characters support the Recent African Hypothesis (all craniofacial characters) and that of 10 characters of questionable validity, 4 arguably show support for the Multiregional Hypothesis and 2 more for the Recent African Hypothesis.

Other studies involving variation in archaic and early modern *H.sapiens* fossils provide contradictory results. For example, Kidder, Jantz and Smith concluded from their multivariate analysis of craniofacial measurements on 49 archaic and early modern European and Near East human fossils that archaic and modern *H.sapiens* cannot be clearly taxonomically separated, a result which supports Multiregionalism (Kidder et al.1992:175). Whereas, Waddle found that a single African and/or Levantine origin for modern humans provides the best explanation for the results of his matrix correlation analysis of cranial variation in archaic and early modern African, European and Near East human fossils (Waddle 1994:452-454).

2.4.3 BETWEEN-GROUPS CRANIOMETRIC VARIATION IN MODERN HUMANS.

In his 1973 and 1989 craniometric analyses of 2504 crania in 28 series representing 6 major geographic regions, Howells showed that variation in cranial shape between modern human populations is small (Howells 1989:71,83). He has recently completed a further investigation of modern human cranial shape variation involving the same data base as in his 1973/1989 studies, new multivariate analysis techniques and an extension of tested material to include skulls representing late prehistoric to archaic *H.sapiens* (Howells, in press). Howells reports that his results not only confirm his earlier

finding of small variation in cranial morphology between all recent modern human populations, but also imply that this homogeneity extends only briefly into the past. He concludes that according to cranial shape, the late prehistoric specimens represent a stage just outside modern humans; a few show recent modern affinities, others are beyond a completely modern conformation. He found no convincing sign of continuity with Neanderthals and other archaic *H.sapiens*. Howells also noted that the variation that does exist between recent modern human groups is not by geographic region but by population, and claims that "populations are the genetic units" (Howells, in press).

As for craniometric variation, genetic variation between modern human groups also has been found to be small, far less than genetic variation within groups (Stringer & Andrews 1988:1264; Bilsborough 1992:213,214). There is no direct relationship between speciation and morphological change (Tattersal 1986:166), and morphological similarities do not necessarily correspond to genetic similarities. Does the pattern of craniometric variation in modern humans correspond to the pattern of genetic variation?

A study by Relethford indicates that between major geographical groups in modern humans the degree of craniometric variation is very similar to the degree of genetic variation (based on genetic markers and mitochondrial DNA), accounting for only 10% of the total variation (Relethford 1994:58-60). His study drew on Howells' data base, and included 1734 crania from 6 world regional groups Relethford concluded that while the existence of low morphological variability between modern human populations of major geographic regions does not exclude the multiregional model of modern human origins, it is more readily explained by a recent divergence from an (African) modern human population. An earlier African origin and gradual regional evolution into modern human form would require a higher rate of gene flow between regions and a larger than feasible population size (Relethford 1994:61).

2.4.4 WITHIN-GROUP CRANIOMETRIC VARIATION IN MODERN HUMANS.

The greatest degree of modern human mtDNA variation has consistently been shown to occur within African populations. Relethford and Harpending have pointed out that this may have

other implications besides earlier divergence; population size, population expansion, migration rates, gene flow rates are other possible factors (Relethford & Harpending,1994:251). What of morphological within-group variation?

Relethford and Harpending devised a model of within-group morphological variation, and applied it to craniometric data for recent modern human groups, Sub-Saharan African, European, Far East and Australasian. They found significantly greatest within-group morphological variation in Africa, and attributed it to the long term population size being greatest in Africa -- approximately 3 times greater than any of the other regions (Relethford & Harpending 1994:258,260). These results which agree closely with the mtDNA and genetic marker evidence were regarded as reflecting either

(i) a more recent common ancestor for non-African populations, thus supporting a recent replacement model which involves an early separation of African from non-African populations, and a late separation of European from Asian populations. This interpretation is in close agreement with several genetic studies (Cavelli-Sforza 1988:6005, 1991:74; Bowcock et al.1991:839,840; 1994:455).

or (ii) long term migration patterns such as a higher rate of migration between non-African populations than between African and non-African populations, Europe being quite isolated from Africa for much of the past. This accords with Bowcock et al.'s conclusion of greater gene flow into Europe from Asia than from Africa, based on DNA polymorphisms showing Europeans to represent a mixture of early Asian and early Africans (Bowcock et al.1991:841). This interpretation of results is consistent with either the replacement model or the multiregional model. However, the multiregional model would need modification to permit different degrees of contribution to later humans from different *H.erectus* and/or archaic *H.sapiens* populations, and is less likely in terms of the probable population sizes and demands of population spread (Relethford & Harpending 1994:260,263,267).

The combined findings of Relethford and Harpending in their analyses of modern human craniometric variation and mtDNA sequence variation make a strong case for their modified Out of Africa Model, -- the WEAK GARDEN OF EDEN Hypothesis. An earlier expansion at about 100 ka ago of the ancestral

African population is consistent with the larger population size and greater within-group variation observed by Relethford and Harpending in African populations. A recent dramatic expansion in populations isolated from each other for so long is consistent with the observation of between-group differences being much less than within-group differences.

The model of Relethford and Harpending, based on genetic and craniological evidence, is in good agreement with Klein's interpretation of the archaeological evidence which he sees as most compatible with a "spread and replacement" hypothesis and involving a major breakthrough in human behaviour about 40,000 years ago (Klein 1992:5,12).

2.5. EAST ASIAN AND AUSTRALASIAN EVIDENCE

Aiello holds that if there is convincing evidence for regional continuity outside Africa in support of the multiregional view, it is in Australasia and east Asia that it is most likely to be found (Aiello,1993:87). Wolpoff sees Asia as "the ideal testing ground" for conflicting hypotheses and claims morphological continuity is identifiable from Chinese *H.erectus* to modern Chinese and from Javan *H.erectus* to modern Australians (Wolpoff & Nkini 1985:205; Wolpoff et al. 1984:411,412; Frayer et al.1993:21).

Numerous studies have tested the validity of a variety of morphological or craniometric features as indicators of continuity from Asian H.erectus to (a) modern Chinese or (b) modern Australians. But the problem is far from resolved. Among those who claim to have identified continuity traits in the Chinese sequence or the Australian sequence or both are: Weidenreich 1943:248,252-254, 1945:21,30; Thorne 1971:85,88, 1976:109,110; Thorne & Macumber,1972:316; Thorne & Wolpoff 1981:337,342-348, 1992:30,31; Wolpoff 1989a:79-83, 1992a:42; Wolpoff & Thorne 1991:39; Pope 1988:61,62,70, 1991:189,208-210, 1992a:3, 1992b:243,289-291; Kramer 1990:253, 1991:455; Wu 1992:373-375; Wu & Dong 1985:88; Wu & Wu 1985:104,105; Frayer et al.1993:21,23.

Habgood recognises continuity in Australasia and more weakly in China not in individual features, but in a suite of features (Habgood 1985:89;1989:267,268;1992:283).

Other researchers found that the features they examined could not be regarded as continuity traits: none are exclusive

to Mongoloid or Australian modern populations, some appear with higher frequency in other populations or are simply size-dependent or related to general robusticity, many are merely retained primitive features so of no phylogenetic value. The following are among such investigators: Larnach & Macintosh 1974:101,102; Macintosh & Larnach 1976:114,124; Stringer 1985: 294, 1990b:34,35,1992:15-19; Rightmire 1988:257, 1992:48,49; Kamminga & Wright 1988:739,753; Kamminga 1992:379; Wright 1992:128,133; Groves 1989:280-283; Howells 1989:83, in press; Storm 1991:198; Storm & Nelson 1992:37,44; Lahr & Foley 1992: 104,1994:50; Lahr 1994:23,34,35,41,48-50; Lieberman 1995:176.

Turner sees Australian dental morphology as of crucial importance to the debate (Turner 1992a:143,150). From dental evidence, he considers that a single modern human origin is the most parsimonious solution, but in Southeast Asia, not in Africa (Turner 1987:317-319; 1989:70; 1992a:149, 150; 1992b:432,433). Turner recognises two modern human dental morphologies in eastern Asia and the Americas, Sinodonty and the more ancient Sundadonty. Sundadonty originated in SE Asia from a more generalised pattern shared by early moderns. From Southeast Asia, Sundadonty or proto-Sundadonty spread into Australasia, and into southern China. In southern China subsequently it developed into Sinodonty, a more specialised dental pattern which eventually spread north into Siberia and the Americas. Other modern human dentitions in other regions, also evolved from the more generalized Sundadont morphology. Though Turner regards modern African dental morphology as far too extreme to have given rise to Sinodonty, he is less certain about its relation to Sundadonty and present Australo-melanesian dental morphology. Although he considers dental evidence points to S.E.Asia as the most probable centre of origin of modern humans, his judgement on a possible African-Australian link awaits the results of further analysis of Australian dentition. (Turner 1989:71-73; 1990:296,314-316; 1992a:145,149,150; 1992b:415,425,426). Hanihara suggests Sinodonty may have developed from Sundadonty as a cold climate adaptation (Hanihara 1994:418).

Stringer acknowledges Australasian evidence presents the greatest challenge to the Out of Africa model, particularly in the extreme variation found in Australian fossils from 10-30 ka ago (Stringer 1990b:37, 1992a:15). But it is also a problem

for multiregionalism. Many recognise two distinct Australian morphologies in that period, the earlier one being gracile (e.g. Lake Mungo, 25ka ago) and the other robust (e.g. Kow Swamp, 12 ka ago). One robust cranium from Willandra Lakes, WLH50, although undated is considered by Wolpoff to be at least as old as the gracile Lake Mungo material (Wolpoff 1992a:42). Gracile and robust forms coexisted in the south east of Australia at least in the terminal Pleistocene (e.g.gracile Keilor and King Island, robust Kow Swamp and Coobool Creek) (Jones 1973:278,280; Brown 1989:5-7,1981:166; Sim & Thorne 1990:55).

Brown considers that tooth size, vault thickness and craniometric evidence indicate the variation is consistent with a single homogeneous Pleistocene population, and that artificial cranial deformation, trauma and a pathological condition contributed to the degree of variation (Brown 1993:225,1989:98,1988:55,1987a:61,62,1987b:189,1981a:166; Webb 1990:403,410). Out of Africa proponents are among those who explain the morphological variation as having rapidly developed as a result of genetic and environmental factors after entry into Australia of the one original modern human founding population (Stringer 1992a:15). On the evidence of non-metric traits, Pardoe concluded that the immense diversity is consistent with differences in social organization, demography and environment (Pardoe 1990:59). Pietrusewsky found craniometric evidence of two distinct morphologies but concluded the variation was clinal and there was only one modern Australian origin (Pietrusewsky 1979:119, 1984:39,40, 1990:319,333).

Among multiregional interpretations of the diversity is the proposal of a dual origin, the robust Australians being seen as descended from Javan *H.erectus*, the gracile from Chinese *H.erectus*. The Holocene morphological variation resulted from admixture within Australia following separate migrations from Indonesia and east Asia, the Indonesian ancestry predominating (Thorne 1971:88,89; Wolpoff et al.1984:446). More recently, multiregionalists stress the similarity in certain morphological features of the robust Australian fossils and Javan *H.erectus* as evidence of continuity in Australasia (Thorne & Wolpoff 1981:337, 1992:29; Wolpoff & Thorne 1991:39), and leave aside the question of the

more gracile Australian fossils (Brown 1993:225).

Macintosh and Larnach viewed the 2 morphologies as representing the 2 extremes of the one population. Although they observed some tendency for certain *H.erectus* traits to persist more in Australians than in other modern humans, they attributed this to the Australians being the first generalised modern humans to reach their ultimate region and furthermore concluded that Australians differ far less from other modern human groups than all do from Ngandong (Macintosh 1967:97, Larnach & Macintosh 1974:101, Macintosh & Larnach 1972:4, 1976:114,118,121,122,124).

Several studies have confirmed close affinity of modern Australians and Melanesians and indicate an Australo-Melanesian complex well-differentiated from Asians and surrounding populations (Howells 1976:641,648, 1989:72; Pietrusewsky 1983:12,61, 1984:40,41, 1990:319,333; Turner 1992a:149; Wright 1992:133).

2.6 THE TEMPORAL BONE AND CONTINUITY IN EASTERN ASIA

Both Weidenreich and Santa Luca in their detailed descriptions of Asian *H.erectus* crania considered the temporal region as quite distinctive (Weidenreich 1943:200-203,231, 1951:269,271-277; Santa Luca 1980:105,107-110). Yet few studies investigating the possibility of continuity in Southeast Asia have paid much attention to the temporal bone. Most have dealt with overall cranial dimensions and superstructures; others concentrated on craniofacial, dental or mandibular evidence.

Macintosh and Larnach are notable exceptions. In separate studies they compared modern Australians with *H.erectus* in general and Ngandong in particular on the basis of features which include the following temporal traits:
a low, straight temporal squamous suture, small mastoid, wide digastric fossa, convex tympanic, suprameatal tegmen presence, postglenoid process absence, entoglenoid process composition and the orientation of the Glaserian fissure, petrous pyramid, tympanic plate and long diameter of the EAM (Larnach & Macintosh 1974:97; Macintosh & Larnach 1972:5). Their method of assessment was wholly non-quantitative, though most of these features are continuous and perhaps better evaluated quantitatively. In some statistical analyses, one or two

mastoid process dimensions (usually length only) have been included among many non-temporal features (e.g. Howells 1973:35, 1989:6; Wright 1990:4, Kamminga & Wright,1988:749; Stringer 1993a:183). Lahr included the petrous-tympanic angle and suprameatal tegmen in the group of features she evaluated (Lahr 1992:58,1994:32,33). None of these studies produced results which the investigators concluded support continuity in Australasia.

Brauer and Mbua (1992:80) and Kennedy (1991:377) included mastoid fissure presence and medial recess presence in the features they evaluated as possible autapomorphs of Asian *H.erectus*; Kennedy also included tympanic plate thickness. Their studies focused on variation in *H.erectus* and in the comparison with variability of the features in other hominids, but only Kennedy included modern humans, restricting that aspect of the study to one population sample only (Kennedy 1991:387-389,400-403). In eliminating the features as possible Asian *H.erectus* autapomorphs, they have shown the features cannot be used to discount Asian *H.erectus* as a possible modern human ancestor. But their results do not thereby confirm Asian *H.erectus* in that role nor lend support to the existence of continuity in the region. Their findings are considered in more detail in Chapter 8, Section 8.1.2 where possible *H.erectus* autapomorphs are examined.

Wolpoff included one temporal feature, mastoid height to width shape, among 12 features in a qualitative study in which the modern Australian fossil WLH50 (late Pleistocene, undated) was compared with African archaic *H.sapiens* Ngaloba, 100-130ka ago, and "the Ngandong sample"(individuals not specified), ~100 ka ago. All 12 features were judged to link WLH50 to "the Ngandong sample", none to Ngaloba (Frayer et al. 1993:23,24). A similar study involving more than 1 representative of African archaic *H.sapiens* and with a quantitative approach would be very interesting.

2.7 SUMMARY

Since the initial formulation of the two extreme hypotheses, Out of Africa and Multiregionalism, a wealth of new genetic, fossil, archaeological, and dating information has emerged and been evaluated. Integration of the new data and attempts to explain the finer details of the story of

modern human origins have resulted in many and invariably more complex hypotheses. Most are closely associated with either Multiregionalism or Out of Africa; some incorporate both, allowing for replacement in one region, continuity in another. The Multiregional and Out of Africa models themselves have evolved to accommodate the new insights.

What has remained constant is the central significance of regional continuity to both these extreme models and to all models based on them. If morphological continuity can be demonstrated to exist uniquely between the archaic representatives in one (non-African) region and the modern human population in that same region, then that modern human population had local and not recent African modern origins, and multiregionalism has been supported. However, the morphological features cited must be not only non-adaptive; they must be shared-derived characters, not merely symplesiomorphies (retained primitive features), and should be relatively functionally independent of each other. If not occurring exclusively in that region's modern human population, the features must either occur with highest frequency in that population or with significantly different mean values (Bilsborough 1992:231; Brace & Hunt 1990:354; Groves 1995:179; Lahr 1994:31; Wood 1994:525).

2.8 AIM

The aim of this study is to bring new evidence to bear on human origins in general and the origin of the Australian aborigine in particular by

1. examining the variation existing between recent modern human populations in a number of temporal bone features.

2. assessing in the light of variation in the temporal bone and especially in relation to the Australians, probable affinities of and significant differences between modern human populations.

3. evaluating if any temporal bone features indicate the existence of morphological continuity in eastern Asia, in particular from Asian *H.erectus* to the modern Australian aborigine.

Chapter 3

ANATOMY OF THE TEMPORAL BONE

3.1

ANATOMY OF THE ADULT MODERN HUMAN TEMPORAL BONE

The temporal bone is one of the most structurally and functionally versatile bones in the modern human cranium. It articulates with at least 5 other main cranial bones, the parietal, occipital, sphenoid, malar, mandible and in some cases the frontal. The diversity of shapes found within its irregular overall shape testify to the variety of functions associated with the temporal bone. It comprises 3 main parts: the Squamous, Mastoid and Petrous portions Figs.3.1.1-3.

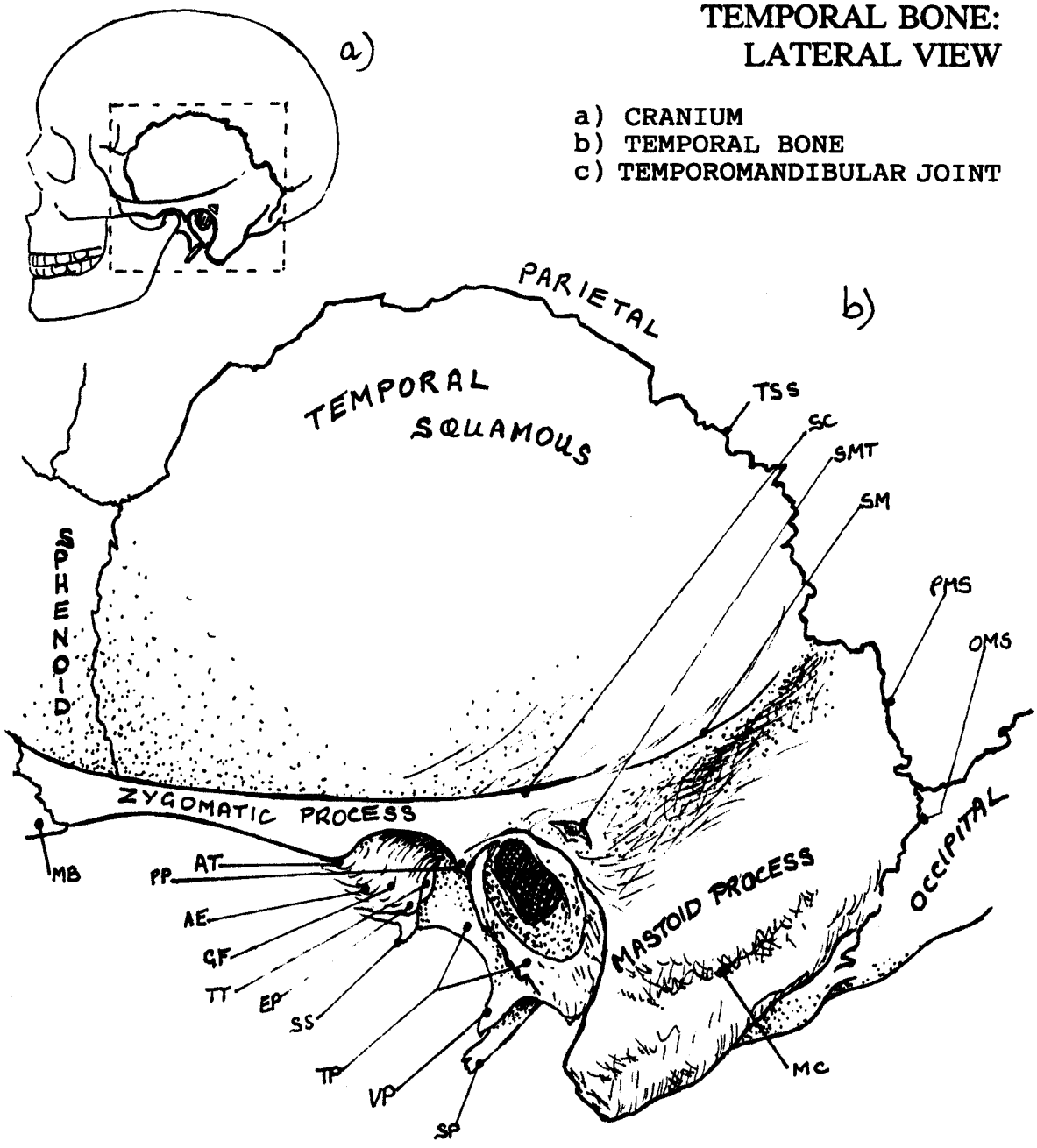
3.1.1 The SQUAMOUS PORTION of the temporal bone forms part of the lateral wall of the cranial vault, overlapping the parietal and meeting the sphenoid (and more rarely, the frontal) at the *squamosal suture* (Fig.3.1.1b). It has a long thin lateral projection, the *zygomatic process*, which articulates anteriorly with the malar bone. Temporal fascia attach to the superior edge of the zygomatic process and the masseter muscle fibres to the inferior edge.

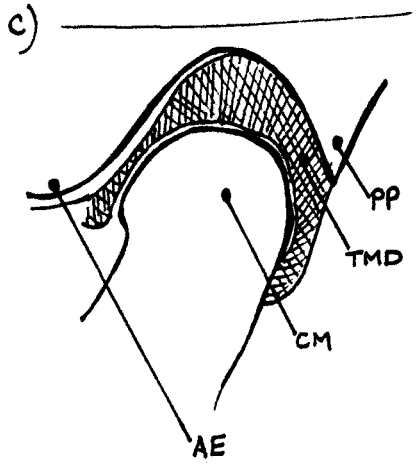
The zygomatic process merges with the rest of the squamous portion through 3 roots. The *anterior root* runs transversely inwards forming the *articular eminence*, which marks the front boundary of the glenoid fossa. At the point where the anterior root diverges from the zygomatic process is found the articular tubercle to which the lateral ligaments of the lower jaw attach. The *middle root* forms the outer boundary of the glenoid fossa and terminates in the *postglenoid process*, the posterior limit of both the glenoid fossa and the temporomandibular joint capsule. The *posterior root* forms a ridge directly above the external auditory meatus known as the *suprameatal crest* which arches upwards and backwards to the squamosal suture as the *supramastoid crest*. The edge of these crests marks the limit of the temporalis muscle and temporal fascia attachments.

The *glenoid fossa* (also called mandibular or articular fossa) is the socket for articulation with the *mandibular condyle* of the lower jaw. The tympanic plate of the petrous

Fig.3.1.1 ADULT MODERN HUMAN TEMPORAL BONE: LATERAL VIEW

a) CRANIUM
b) TEMPORAL BONE
c) TEMPOROMANDIBULAR JOINT





AE....Articular eminence
AT....Articular tubicle
CM....Condyle of the Mandible
EP....Entoglenoid process
GF....Glenoid fossa
MB....Malar bone
MC....Mastoid crest
OMS...Occipitomastoid suture
PMS...Parietomastoid suture
PP....Postglenoid process
SC....Suprameatal crest
SM....Supramastoid crest
SP....Styloid process
SS....Sphenoid spine
SMT...Suprameatal triangle
TP....Tympanic plate
TSS...Temporal squamosal suture
TMD...Temporomandibular disc
TT....Tegmen tympani
VP....Vaginal process

portion constitutes the posterior wall of the glenoid fossa. A narrow slit, the *Glaserian (squamotympanic) fissure*, identifies the junction of the anterior squamous portion and the posterior petrous portion of the glenoid fossa (Fig.3.1.2b). The *entoglenoid process* is the inferior projection of the glenoid fossa at the medial edge of the articular eminence; this occasionally forms a prominent spine.

An *articular disc* of dense fibrocartilaginous tissue is interposed between the temporal bone and the mandibular condyle (Fig.3.1.1c). Although the temporomandibular joint (TMJ) is a stress bearing joint, the thinness of the glenoid fossa roof is evidence that this is not a major stress bearing portion of the TMJ (Hylander 1992:61,62). The shape of the glenoid fossa is related to incisor occlusion, a deep overbite being associated with a deep fossa, steep articular eminence and constrained lateral movements. The shape may be modified in the adult; for example, with tooth loss or severe attrition the slope of the articular eminence would tend to decrease and the fossa become more shallow (Aiello & Dean, 1990:89).

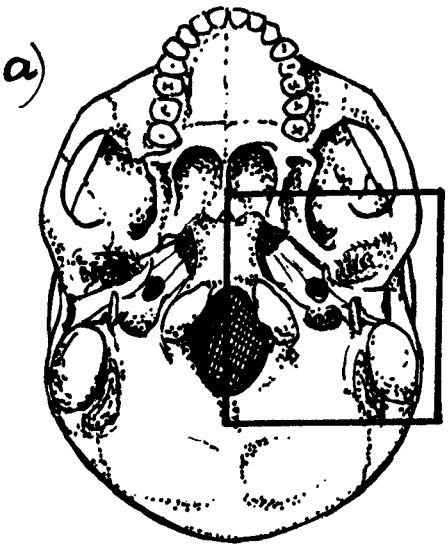
3.1.2 The MASTOID PORTION of the temporal bone extends below and posterior to the supramastoid crest (Fig.3.1.1b,2b). It is bounded posteriorly and medially by *parietomastoid* and *occipitomastoid* sutures and anteriorly at its conjunction with the tympanic plate. The lateral end of the *tympanomastoid fissure* (= "*auriculare fissure*"; Gray 1994:32,33,512) is likely to be closed or no more than a fine slit.

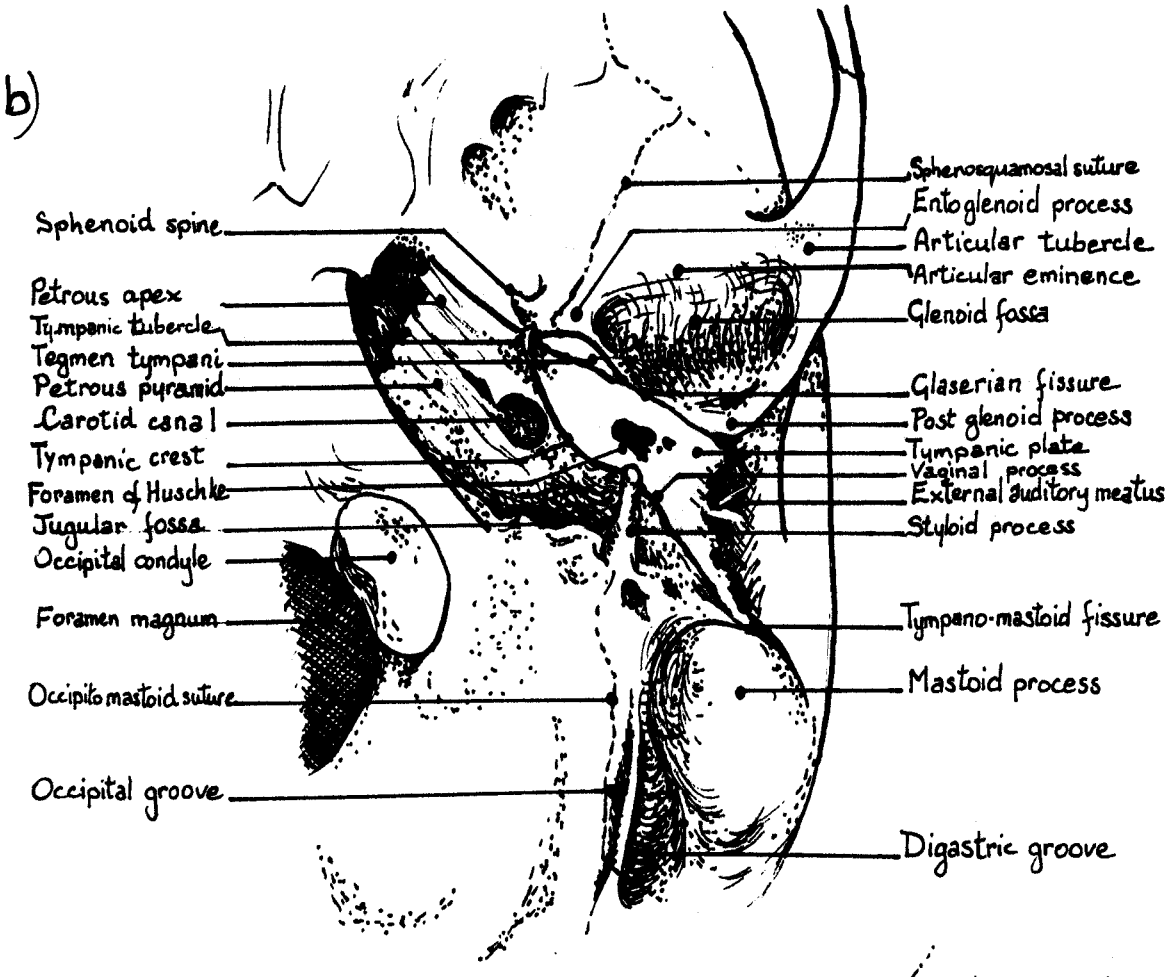
The *mastoid process* is the inferior conical projection of the mastoid portion. Attached to its rough lateral surface are several muscles including the *sternocleidomastoid* (along the *mastoid crest*), the *splenius capitis* and the *longissimus capitis* which function in the extension and rotation of the skull. On the medial side of the mastoid process, the *digastric muscle* attaches in the *digastric groove* and close to the occipitomastoid suture, the finer *occipital groove* carries the *occipital artery* (Fig.3.1.2b).

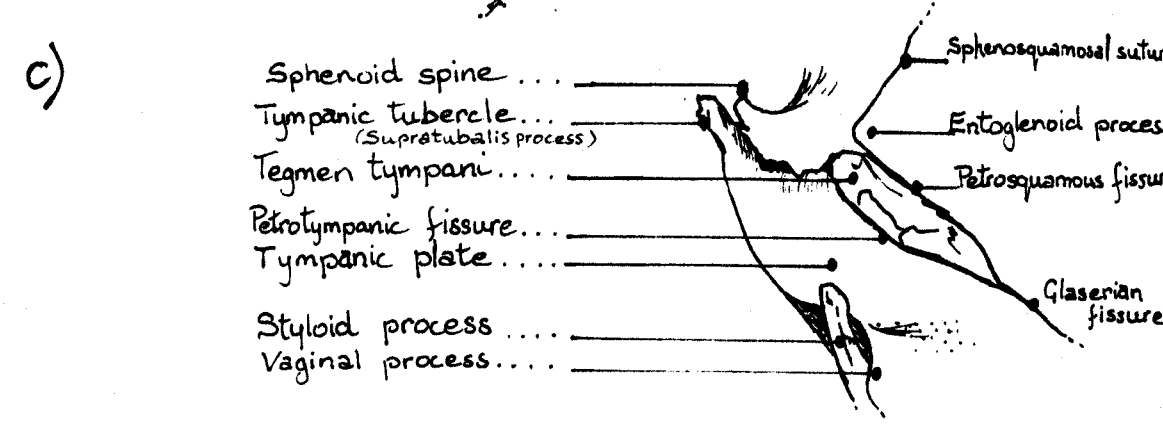
Internally the mastoid process is occupied by numerous, small, irregularly-shaped, interconnecting air spaces called *mastoid cells*. Lined with the same mucous membrane as in the tympanum (middle ear), the mastoid cells also connect with a larger air sinus, the *mastoid antrum*, which in turn opens into

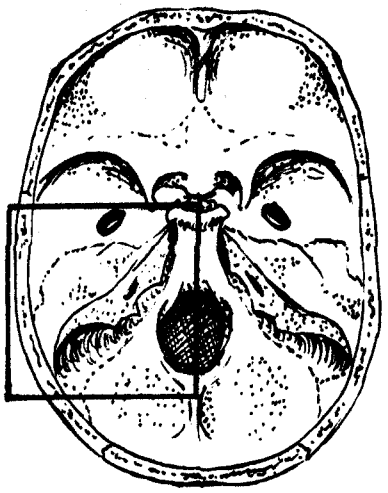
Fig.3.1.2 ADULT MODERN HUMAN TEMPORAL BONE: BASAL VIEW

a) CRANIAL BASE
b) TEMPORAL REGION
c) TYMPANIC-GLENOID-SPHENOID CONJUNCTION







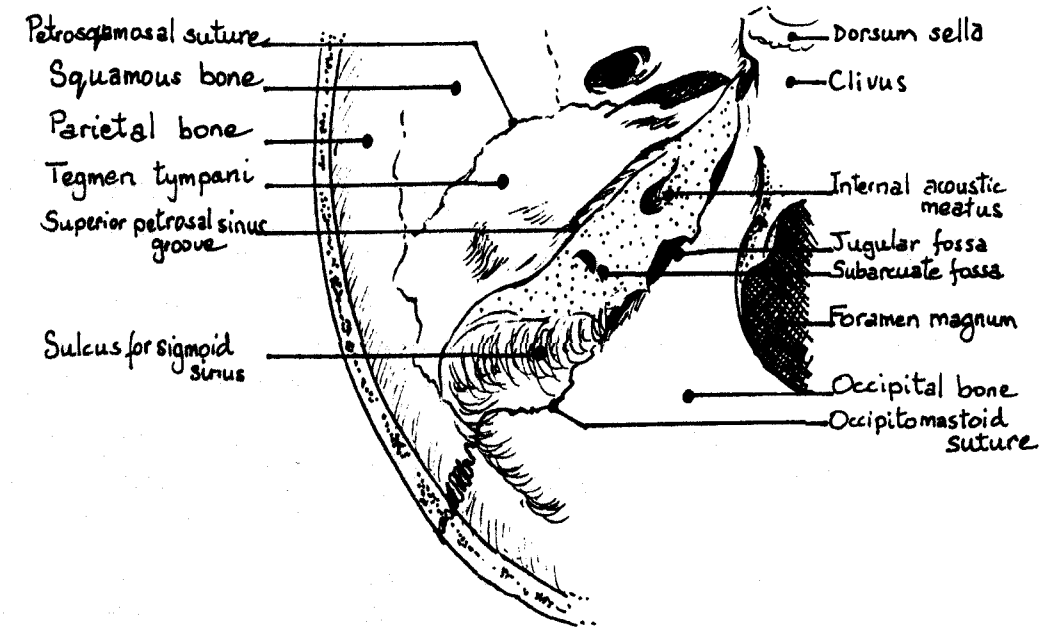


a)

Fig.3.1.3 ADULT MODERN HUMAN TEMPORAL BONE: ENDOCRANIAL VIEW

a) CRANIAL BASE
b) TEMPORAL BONE

b)



the middle ear cavity. Mastoid cells are thought to play a secondary role in the function of hearing.

The concave endocranial surface of the mastoid corresponds to a section of the *sigmoid sulcus* wherein is lodged the *sigmoid sinus*, a major vessel draining blood from the brain into the *jugular vein* which emerges from the cranium through the *jugular fossa* (Fig.3.1.3). The fact that the right sigmoid sulcus tends to be larger than the left at least partly accounts for the observation made in the asymmetry analysis (Section 4.4.1.2, Appendix Table A.4.13) that the right mastoid process is larger than the left, especially in depth and width.

Human males tend to have a larger, more robust mastoid process than females (Gray's Anatomy 1989:395; Lanarch & Freedman 1964:296). This feature is related to the generally more robust nature of male musculature.

3.1.3 The PETROUS PORTION of the temporal bone, the *petrous pyramid*, is situated between the sphenoid and occipital bones, is aligned anteromedially and ends anteriorly in the *petrous apex* (Fig.3.1.2b). The petrous pyramid's special functional association is with equilibrium and hearing. It is an exceptionally dense and robust bone consisting of 4 different layers. The outer periosteal layer, composed of spongy and compact bone in which collagen fibres run parallel to the bone surface, is adapted to minimise mechanical stress and resorb elastic deformation. By contrast, the 3 inner layers being highly mineralised and containing a web-like arrangement of collagen fibres, are resistant to bone remodelling; the 3 inner layers together form the *labyrinthine capsule* which houses the organs of hearing (Doden & Halves1984:451,457,461).

The inner ear (*labyrinth*), is the essential part of the hearing organ. It consists of vestibule, semicircular canals and cochlea and receives the ultimate distribution of the auditory nerve. The middle ear (tympanum or tympanic cavity) contains the tiny ear ossicles, the malleus, incus and stapes, which convey the vibrations communicated to the tympanic membrane across the middle ear cavity to the inner ear. The malleus bone is attached to the membrane, drawing it in so that its outer surface is concave, the inner surface convex.

The internal *carotid artery*, supplying most of the blood

to the brain, and the *carotid plexus of nerves* pass into the petrous pyramid via the *carotid canal* and emerge at the apex above the *foramen lacerum*. The petrous bone also completes the anterolateral part of the *jugular foramen* and *fossa*.(The posteromedial margin is occipital bone.)

Considering the endocranial aspect, the sharp superior edge of the petrous surface anteromedially separates the occipital and temporal lobes of the brain (Fig.3.1.3). The *internal acoustic (auditory) meatus*, situated midway along the posterior petrous surface, transmits acoustic and facial nerves and the *internal auditory artery*.

Though of separate origin, the TYMPANIC part of the temporal bone is usually considered with the petrous portion. The *tympanic plate* is a smooth curved surface of bone anterior to the mastoid, posterior to the glenoid fossa, internally fusing with the petrous (Figs.3.1.1b,2b). It forms the anterior wall, floor and lower posterior wall of the external acoustic (auditory) meatus; the lateral edge (the rim) is roughened for the attachment of the cartilaginous part of the external ear.

The tympanic plate anterior surface is thinnest at the centre where occasionally there occurs a dehiscence, small or large, known as the *foramen of Huschke*. This feature has been found to be more common in females than in males; the frequency of occurrence in different populations varies considerably (0-55%). It has been claimed, but is not generally agreed that this deficiency is genetically determined (Anderson 1962:152; Hauser & De Stefano 1989:143-147).

The anterior (usually concave) surface of the tympanic plate forms the posterior wall of the glenoid fossa, meeting the squamous part of the fossa at the *Glaserian (squamotympanic) fissure*. (Figs.3.1.2b,c). A small section of the petrous bone forming the downward curved roof of the middle ear, protrudes to the exterior between the glenoid fossa and tympanic plate. This tongue of bone, the tegmen tympani, divides the Glaserian fissure at its medial end into 2 new fissures, *petrosquamosal* (anteriorly) and *petrotympanic* (posteriorly).

In basal aspect, the posterior edge of the tympanic plate runs as a sharp ridge, the *tympanic (petrosal) crest*, from its inferiolateral conjunction with the mastoid process, to the

anterolateral rim of the carotid canal and ending in a tubercle (supratubalis process) which may be long or short, fine or thick, spiky or stubby. Approximately midway along the tympanic (petrosal) crest a section of the tympanic plate known as the *vaginal process* may curve to partially ensheathe the *styloid process*, --- a thin rod of bone, variably developed, which anchors the *stylohyoid ligament* and a few small muscles. Otherwise, the tympanic plate is posteriorly fused with the rest of the petrous bone.

3.2 ONTOGENY OF THE MODERN HUMAN TEMPORAL BONE

There are 4 morphologically distinct elements in the temporal bone which ossify independently: *squama*, *tympanic*, *petromastoid* and *styloid process*. The first two are ossified directly from membrane (mesenchyme), the latter two are preformed in cartilage (Figs.3.2.1a-e)

3.2.1 GENERAL DEVELOPMENT OF THE TEMPORAL BONE:

SQUAMA: The first trace of temporal bone development occurs in the 8th. week of gestation when the *squama* begins to ossify in a sheet of condensed mesenchyme from a single centre near the zygoma roots.

TYMPANIC: By the 10th. week a C-shaped *tympanic ring* begins to form from a primary osseous centre and 3 or 4 lesser centres which appear in the mesenchyme, progressing through various stages of enlargement and development. After birth, the ring expands laterally as a *tympanic plate* to form the anterior wall and floor of the external auditory meatus, the non-articular posterior part of the glenoid fossa and the vaginal sheath associated with the styloid process. (A more detailed description of the complex development of the tympanic segment follows in Section 3.2.2.)

PETROMASTOID: The cartilaginous *petrous* segment begins to ossify from multiple centres in the 16-17th. weeks of gestation. Development is rapid; fusion of the centres and complete ossification of the *otic capsule* occur by week 23. The petrous part forms the roof, floor and medial wall of the *tympanum (middle ear)* cavity; the lateral wall is formed from the squama, tympanic and tympanic membrane. Housed within the petrous bone, the inner ear canals and the middle ear ossicles (malleus, incus and stapes) are all fully grown by birth. The labyrinthine capsule does not alter essentially after the age of 2 years (Doden & Halves 1984:460).

The *mastoid antrum*, opening into the middle ear, is also well formed at birth. However, the *mastoid process* does not develop until after birth. It is derived primarily from the cartilaginously preformed petrous and also from *membranous* preformed squama. In the second year the mastoid process is perceptible as merely a slight bulge. Pneumatization started in the mastoid antrum expands into the initially flat mastoid process and as the mastoid air cells develop, the lateral

Fig.3.2.1 ORIGIN AND DEVELOPMENT OF THE TEMPORAL BONE

(After Frazer, 1920: Fig. 172)

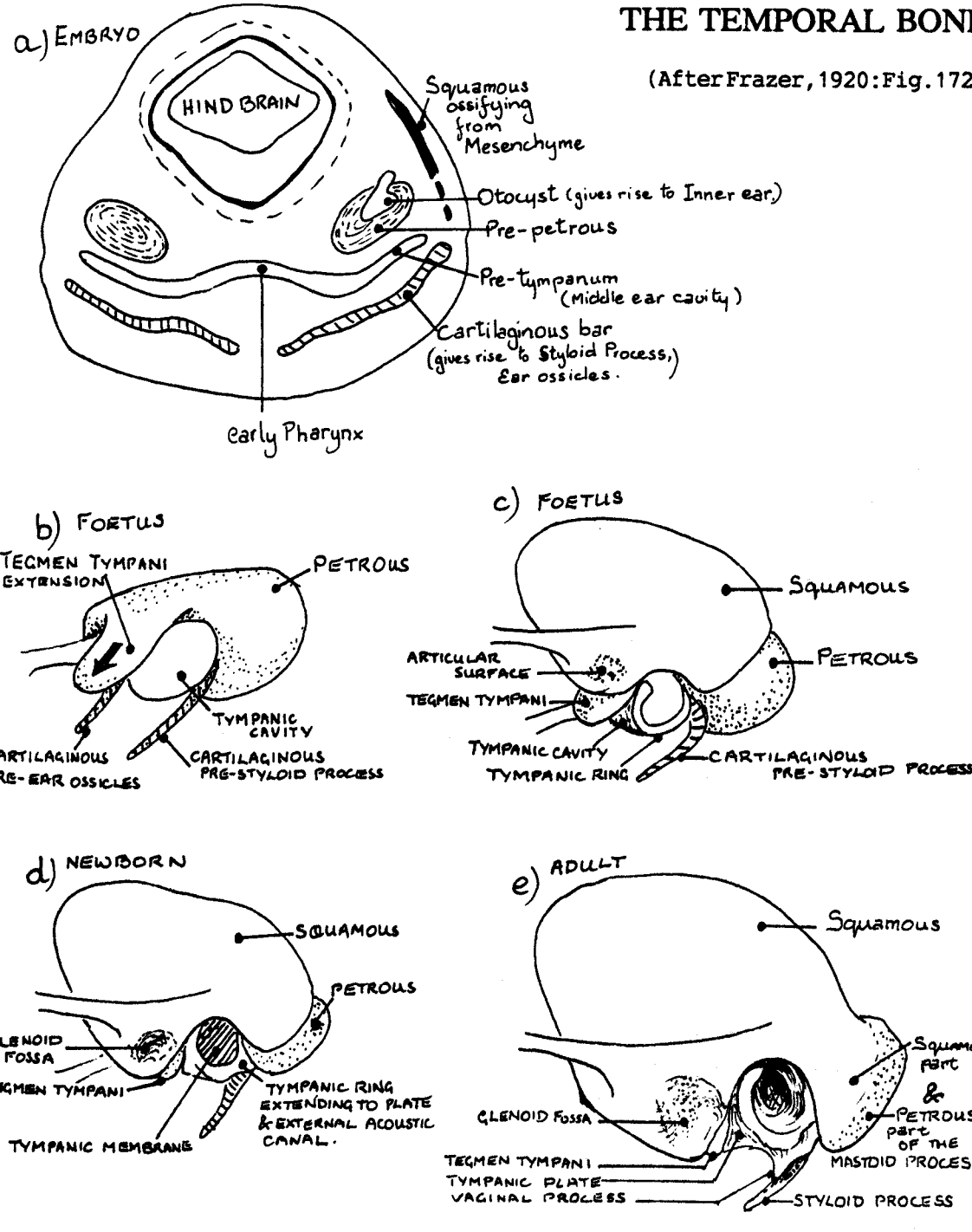


Fig.3.2.2 THE PETROSQUAMOSAL SUTURE

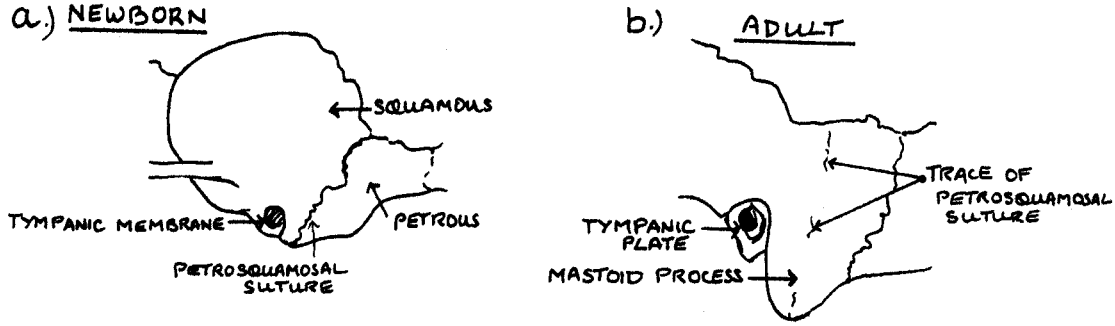
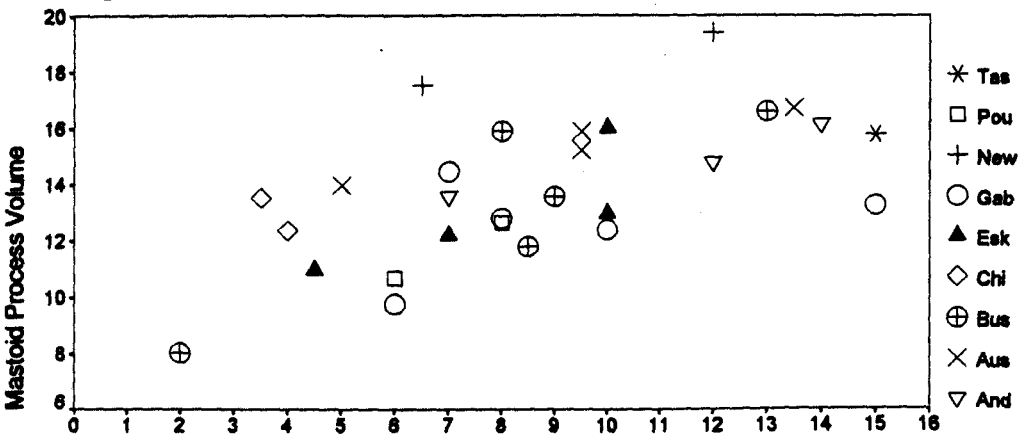


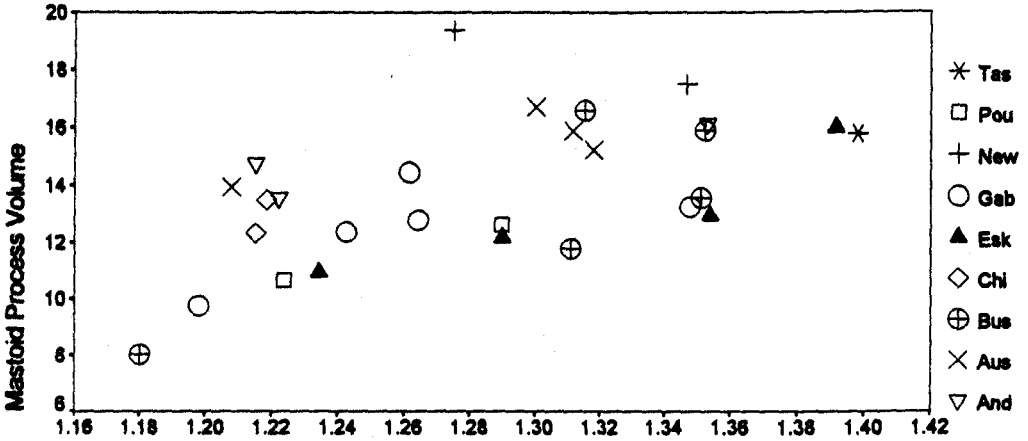
Fig.3.2.3a Mastoid Process Volume Vs. Age



Estimated Age (yrs)

The mastoid process volume increases with age in juveniles.Comparatively small mastoids in Gabon & large in New Britain juveniles are indicated.

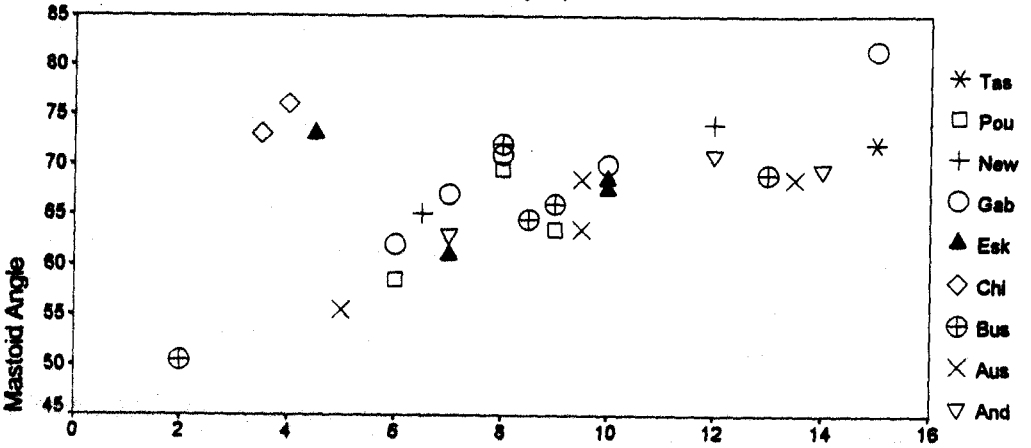
Fig.3.2.3b Mastoid Process Volume Vs. Cranial Size



Cranial Size [cub.rt.(LxBxH)]

The mastoid process volume increases with cranial size in juveniles. The Eskimo juvenile mastoid tends to be small relative to cranial size.

Fig.3.2.4 Mastoid Angle Vs. Age (yrs)



Estimated AGE (yrs)

The juvenile Mastoid Process becomes more vertically oriented with age.

The angle in Chinese juveniles is particularly large relative to age.

mastoid region grows down and forwards to form an increasingly evident conical-shaped projection. The superficial squamomastoid suture usually begins to obliterate by the end of the second postnatal year (Fig.3.2.2a,b. See also Plate 5.1), though it persists in up to 5.7% adults (Hauser & De Stefano, 1989:206). It is not until after puberty that the mastoid cells are fully developed and the process achieves its full prominence. Using data from the juvenile modern human sample (Appendix Table A.4.4), the increase in mastoid volume with age (Fig.3.2.3a) and with cranial size (Fig.3.2.3b) are plotted. Although within the juvenile sample, group sizes are very small, Eskimos juveniles appear to have a comparatively small mastoid relative to cranial size. This has been noted by others (Duckworth 1900:135; Furst & Hansen 1915:49,50), and is a trend which is also true of adult Eskimos as will be shown in Sections 5.3.3.8-11 and 7.1.1.2. The long axis of the mastoid process becomes increasingly inclined towards the vertical with age in human juveniles (Fig.3.2.4).

STYLOID PROCESS: The *styloid process* develops from 2 cartilaginous centres. The upper centre appears just before birth, eventually fusing with the petromastoid; the second centre appears between the 2nd. and 3rd. postnatal year. The 2 centres usually unite in the adult.

3.2.2 DETAILED DEVELOPMENT OF THE TYMPANIC (Anson et al. 1955:803-822; Frazer 1920:209,210,267,269 & Fig.172; Gray's Anatomy 1989:363; Shapiro & Robinson 1980:4,5).

PRENATAL DEVELOPMENT. (Fig.3.2.5) The C-shaped tympanic ring which begins to form by the 10th. week continues to grow in diameter. The outer surface is convex, the inner surface concave. By the 19th. week, the tympanic ring encloses 9/10ths. of a circle, the head end is deeply sulcate, the middle portion flatter. By the 22nd. week, though the tympanic membrane (ear drum) is not yet lodged in the *sulcus tympanicus* of the tympanic ring, the 3 constituent layers of the membrane are formed: external (cuticle), middle (fibrous, elastic) and internal (mucous, derived from the lining of the tympanum).

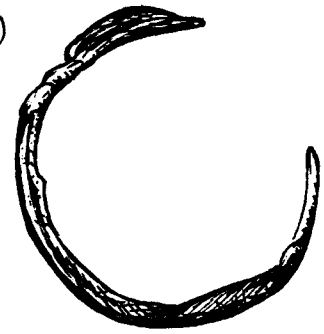
POSTNATAL DEVELOPMENT (Fig.3.2.6-10) The development from birth of the tympanic ring into the tympanic plate has been proposed as a useful guide to aging foetal and infant crania, since it occurs in at least 6 discernible stages (Anderson 1962:144-153; Weaver 1979:263; Curran & Weaver 1982:241).

Fig.3.2.5 DEVELOPMENT OF THE TYMPANIC RING

a)

Week 10 of GESTATION: The ring begins to ossify from 4 centres in the mesenchyme. Ossification centres fuse at 10½ weeks.

b)



Week 16½: Diameter of the ring has tripled. The posterior end is round in cross-ection and smaller than the anterior end.

c)

TYMPANIC RING FOETAL GROWTH	
Age (wks.)	Diam. (mm)
10	2·1
10½	2·6
12	4·2
16½	6·4
19	7·4
TERM	10·0

Anson, et al., 1955: 816

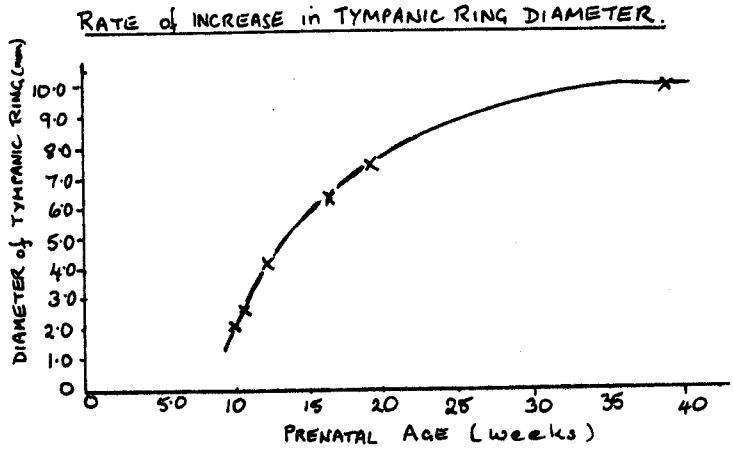


Fig.3.2.6 DEVELOPMENT of the TYMPANIC RIM to the TYMPANIC PLATE and EXTERNAL ACOUSTIC CANAL

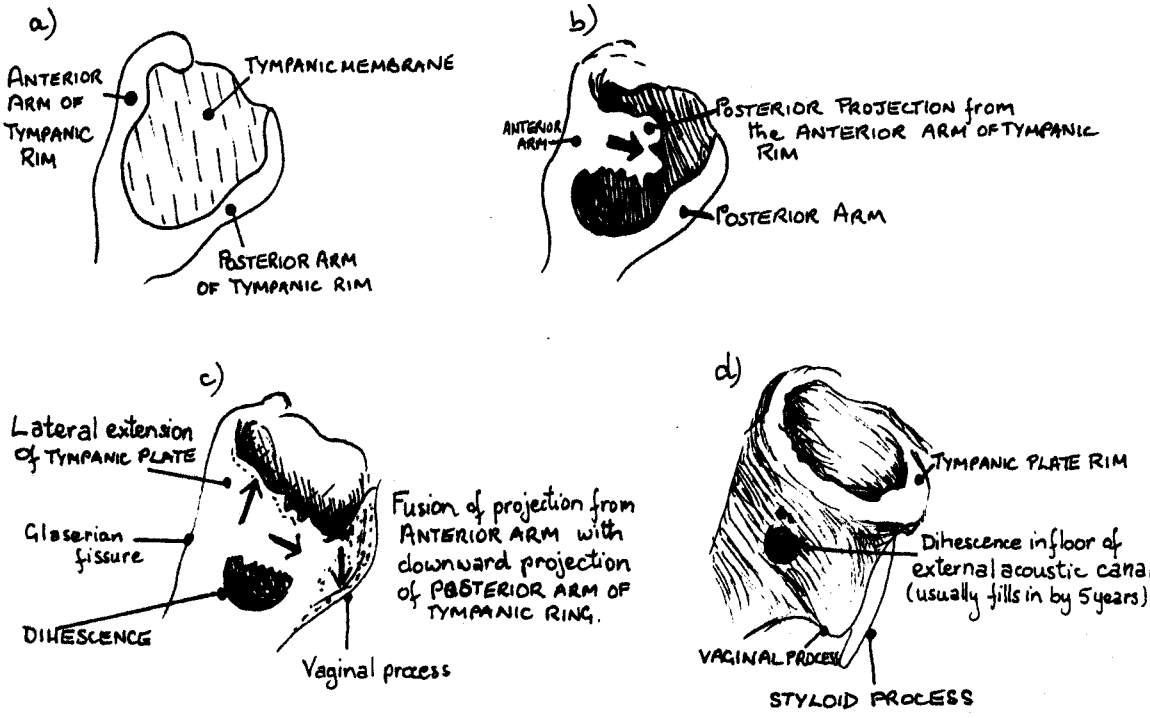
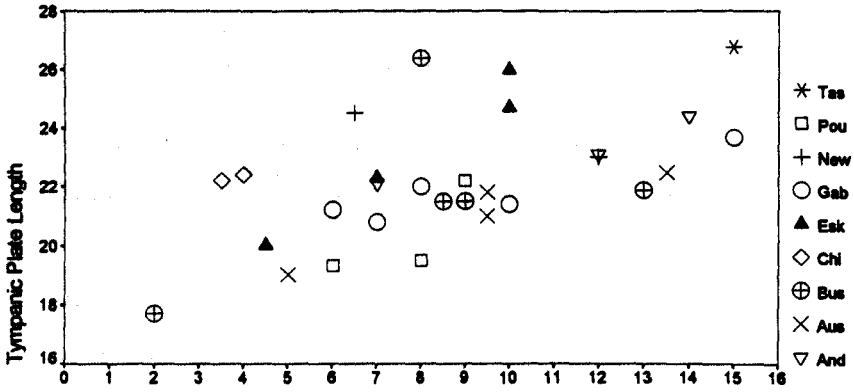
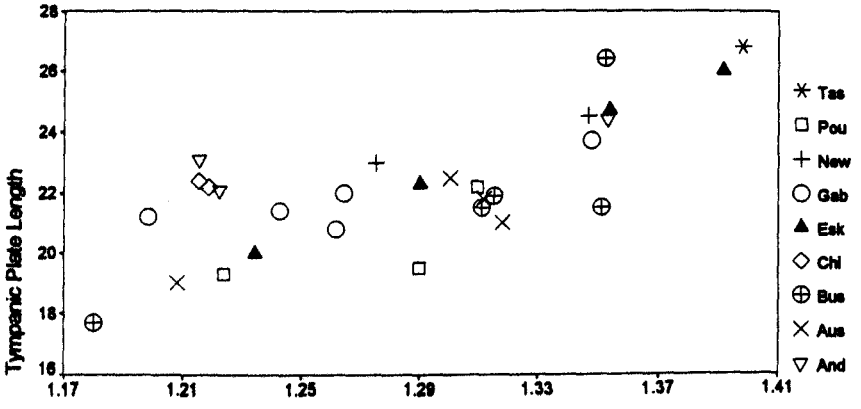


Fig.3.2.7. Tympanic Plate Length Vs. Age



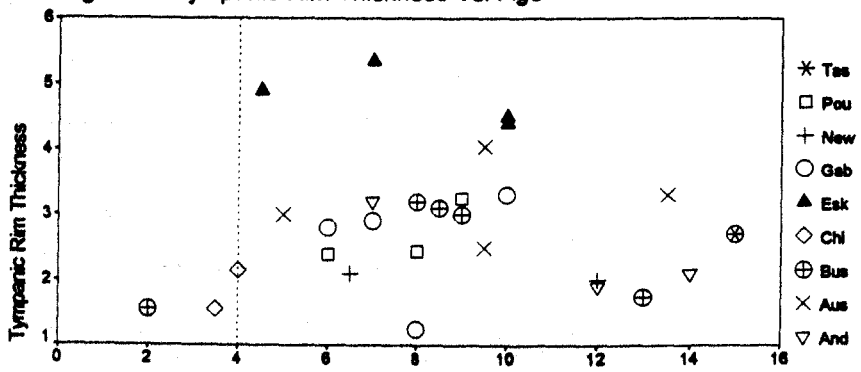
The tympanic plate lengthens with age in juveniles.

Fig.3.2.8. Tympanic Plate Length Vs. Cranial Size



The tympanic plate length increases as juvenile cranial size increases.

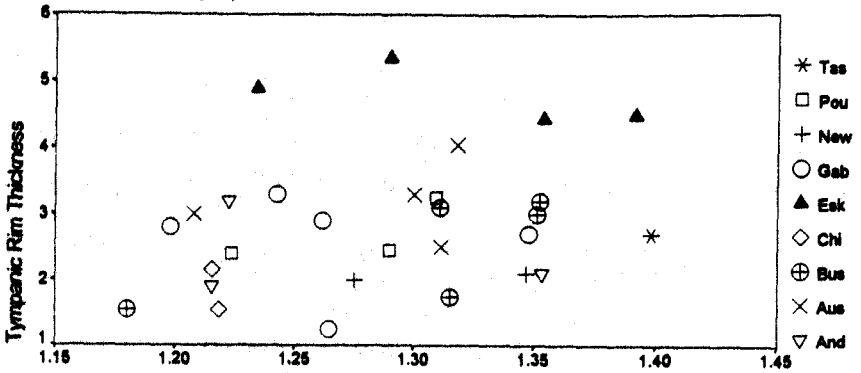
Fig.3.2.9. Tympanic Rim Thickness Vs. Age



The exceptional thickness of Eskimo tympanic rim is evident in juveniles

There is no indication of rim thickness increasing with age after ~4yrs.

Fig.3.2.10. Tympanic Rim Thickness Vs. Cranial Size



The tympanic rim in juveniles does not thicken as cranial size increases

but exceptional Eskimo rim thickness is clear even at this early stage

At birth the tympanic ring has reached adult diameter. Its anterior and posterior sides still do not meet superiorly but the gap is closed by fusion with the squama. The tympanic ring is fully exposed laterally and, like a frame, it now encloses the tympanic membrane (Fig.3.2.6a).

Medially and posteriorly, the tympanic ring fuses with the petrous and squamous parts of the temporal bone, the anterior limb remains free. Irregularities appear in the margins of the anterior and posterior limbs of the tympanic ring. A posterior extension from the anterior limb creates a nearly circular gap (dehiscence) (Fig.3.2.6b). Lateral extension of the anterior segment of the tympanic ring begins to form the floor of the external auditory canal. Meanwhile, the posterior limb is growing downwards.

The posterior process of the anterior limb meets and fuses with the downgrowth of the posterior limb, thus completing enclosure of a foramen in the external auditory canal floor (Fig.3.2.6c). The posterior limb downgrowth also forms a sheath (vaginal process) anterior to the styloid process; ultimately, it extends as a sharp tympanic crest, lateral to the carotid canal anterior rim and anteromedial to the mastoid process.

Continued lateral growth of the tympanic plate produces the anterior wall and floor of the external auditory meatus (Fig.3.2.6d). This also constitutes the non-articular posterior part of the glenoid fossa; as the glenoid fossa deepens, the external auditory meatus lengthens. Usually, the dehiscence in the external auditory canal floor is obliterated by about the 5th. year; if it persists into adulthood it is called the foramen of Huschke. Tympanic plate growth continues into early adolescence at least, as can be seen in the plot of tympanic length with juvenile age (Fig.3.2.7). The lengthening closely matches general cranial size increase (Fig.3.2.8).

The original tympanic ring remains in the adult at the medial end of the external auditory canal as the portion of bony wall supporting the tympanic membrane. At the lateral extreme of the tympanic, the rim thickness does not appear to increase with age or with increasing cranial size, at least not after about 4 years. But the exceptional thickness the rim attains in adult Eskimos compared to other modern humans is evident also in juvenile Eskimos (Fig.3.2.9 & 10, Plate 5.1).

Chapter 4

METHODS AND MATERIALS

4.1 MODERN HUMAN POPULATION SAMPLES

4.1.1 POPULATION SAMPLE SELECTION.

A total of 447 adult crania were measured and represent 11 recent modern human populations of widespread geographic origin (Fig.4.1.1). The crania are drawn from 5 different collections, though most are from the Natural History Museum, London (Appendix Table A.4.1). Since one or more of a few measurements were not able to be taken on a small number of crania, the total sample size was reduced to 443 in the multivariate analyses.

Samples were selected to include populations

(i) representing main geographic regions:
Asia, Europe, Africa(Sub-Saharan), Australo-Melanesian;
(ii) representing a wide range of geographic origin;
(iii) which ensure a wide spectrum of cranial size;
(iv) of close proximity to and/or probable affinity with Australian aborigines.
(v) associated with a wide range of life-style, and habitat.

7 of the samples selected consist of 50 or more crania. The 4 smaller samples are restricted by availability of suitable crania, but are included for one or more reasons: e.g. extreme cranial size (large Fuegian, small Bushman), extreme lifestyle / habitat (Bushman, Fuegian), possible affinity with Australians (Tasmanians, Veddah, Bushman). Inclusion of an Amerindian population sample was desirable but not possible, since sufficient adequately provenanced material was not available.

The identity of each cranium in the 11 samples is recorded in Appendix Tables A.4.2-4, according to catalogue code, population and collection source. Only Poundbury and Gabon collections permitted random selection of crania, and this was qualified by an attempt to ensure approximate sexual

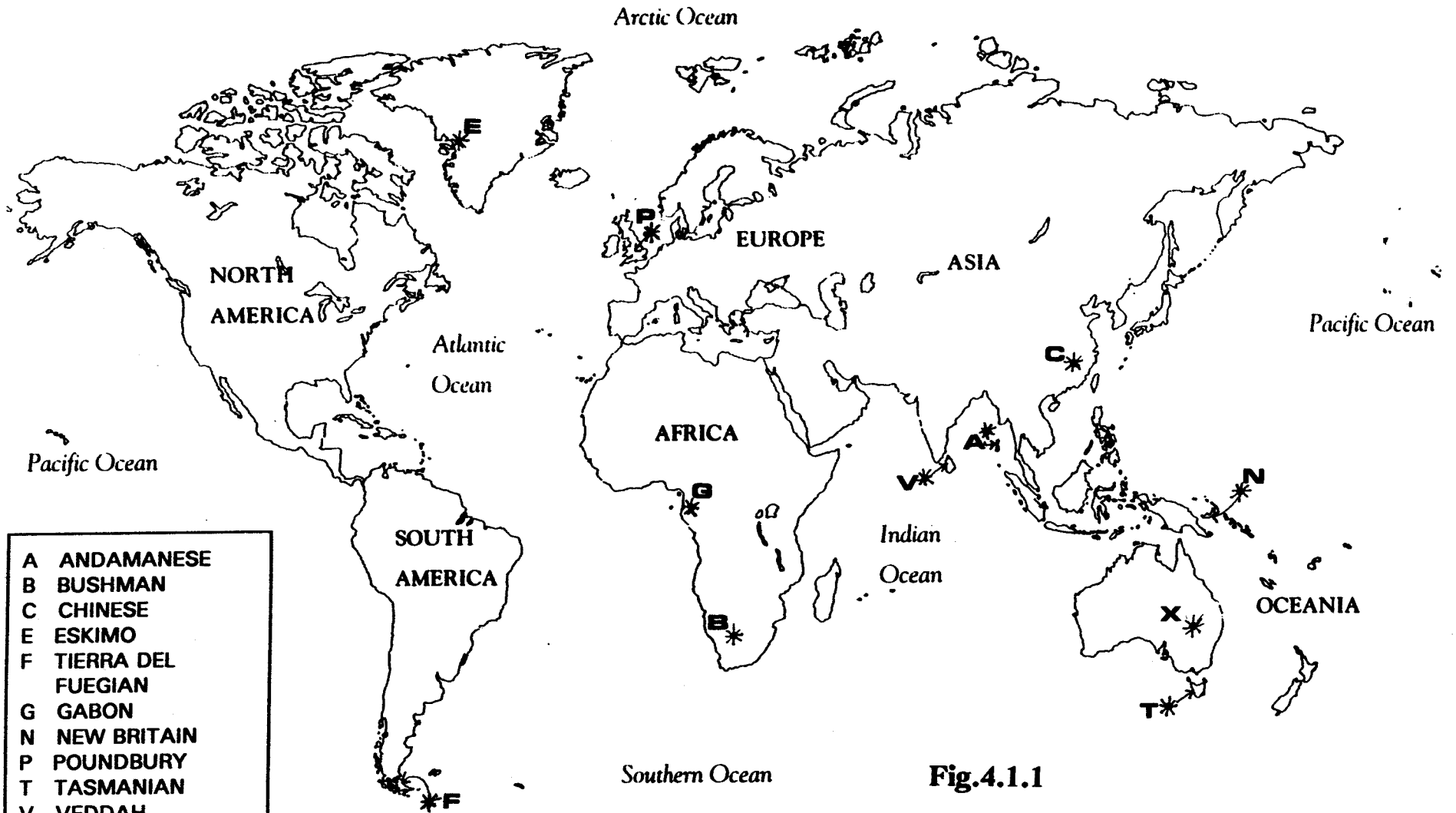


Fig.4.1.1

GEOGRAPHIC ORIGINS: MODERN HUMAN SAMPLE POPULATIONS

equality (see Section 4.1.2). For all other samples, collection numbers were such that all or nearly all crania were used provided the crania were adequately preserved to permit the taking of relevant measurements and no obvious cranial deformity existed.

Occasionally there was reason to doubt that an individual cranium legitimately belonged to the population category to which it had been assigned. Among the means used to clarify the identity of such crania was the computer programme "CRANID" (Wright 1990,1992). It provides a multivariate analysis of cranial shape (estimated from a number of craniometric measurements), comparing the shape of the cranium in question with that of 2,524 crania from 55 worldwide population samples measured by W.W. Howells (1973, 1989). The purpose of "CRANID" is not to provide categorical identification but rather to assist assessment by reducing uncertainty. "CRANID" was particularly helpful in assembling the Tasmanian, Bushman and Australian samples.

4.1.2. SEXING CRANIA

The material was not sexed. A number of considerations contributed to this decision.

(i) The study is not concerned with temporal bone variation within populations or between male and female crania, but rather with variation between populations.

(ii) Previous studies have found that sexes show agreement as to discrimination of populations (Howells 1969:453); males and females from the one population sample are more like each other in shape than either is to another population sample (Wright 1992:133).

(iii) Size differences account almost entirely (up to 98%) for sexual dimorphism (Uytterschaut 1986:243). It is intended to assess the size factor and eliminate it if necessary when applying discriminant analysis to the sample.

(iv) Sex of individual crania could not be assigned with adequate confidence for these reasons:

The amount and reliability of recorded information available about the sex of individual crania varied considerably within and between population samples. Very few crania in any cranial sample in this study were of known sex

and even fewer were associated with postcranial material.

Regardless of the sexing technique and even when applied to only the population from which it was derived, the sex of 10-20% of the crania remain doubtful (Brown 1981:53; Howells,in press). The degree of sexual dimorphism and the overlap of male and female ranges of cranial sex characteristics can vary markedly from one population to another. Consequently, when several populations are involved in a study, it is difficult for the one sexing technique to be equally applicable to all samples[1]. A sex discriminant function is needed which is independent of the population to which it is applied.

In seeking a satisfactory sexing technique of universal applicability, a possible universal sex discriminant function devised by Uytterschaut (1986:243) was tested on a cranial sample of known sex; but it gave a 12.3% overall misclassification rate[2]. (A summary of the results of the analysis is recorded in the Appendix Table A.4.5 and Fig.A.4.1). No sex discriminant function was found which yields greater sexing accuracy than visual diagnosis.

Even though separate analysis of male and female crania in the various samples was not attempted, it was thought desirable to avoid the bias of having samples unevenly weighted with males or females. Visual inspection and reference to all available recorded information were used to ensure this. However, in the 4 small samples for which all available measurable crania were used, sex equality is less certain. In particular, the Tierra Del Fuegian sample appears likely to consist predominantly of male crania.

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[1] e.g. The sex discriminant function used by Giles and Eliot, 1963:67, achieved 82-89% sexing accuracy, but with only 2 known-sex populations; extension to other unknown-sex populations is likely to be less accurate, particularly with small samples, since adjustment of the sectioning point to the bimodality of each population is required.

[2] Uytterschaut proposed a "race-independent" sex discriminant function [= 0.35 GOL + 0.54 ZYB + 0.58 NLH + 0.49 NLB] which he found effective for 3 populations -- Dutch, Zulu and Japanese (Uytterschaut 1986:243). It was applied in this study to a known-sex sample of Spitalfields crania comprising 27 females and 27 males. 87% correct assignment was achieved.

4.1.3 POPULATION DESCRIPTION

AUSTRALIAN: Prior to selecting the Australian and Tasmanian samples, a pilot study was carried out to assess the identity of crania in the Australian collection of the Natural History Museum and involved quantitative analysis of cranial shape, using the computer programme "CRANID" (Wright 1990,1992). On the basis of the results obtained, 7 Tasmanian crania and 69 mainland Australian crania from the NHM collection have been included in this study.

Since the origins of these 69 Australian crania were widely spread throughout the continent, craniometric variation in the Australian sample in this study might be expected to be considerably greater than that of Howells' "nearly ideal" Australian sample derived from a long standing, highly localised population (Howells 1989:95). Yet, since it was on the basis of Howells' precisely defined Australian sample that"Cranid" recognised the 69 NHM crania as Australian, this suggests that craniometric differences between the Australian sample in Howells' study and the one in this study were noticeably less than differences between either sample and other world population samples, including Tasmanians.

A further 7 crania from Cambridge Duckworth Collection were added to the Australian sample.

TASMANIAN: Separated from the Australian mainland for 10,100 years, the inhabitants of the island of Tasmania were the world's longest isolated human population[1]. Their origin and affinities have long been the focus of much speculation; differences between Tasmanian and mainland Australian aborigines were stressed in the early literature. Recent findings suggest that of the two nomadic cultures, that of Tasmanians was the simpler (Morant 1927:426-428; Wunderly & Wood-Jones 1933:584-593; Wunderly 1939:313-331; Diamond 1993:52-56).

Diverse opinions exist as to the implications of the long period of isolation. For example, from a study using non-metric traits, Pardoe concluded that the isolation actually

[1] Tasmania was part of the Australian continent until 55,000 years ago and from 37,000 to 10,100 years ago. The oldest known human site in Tasmania is 35,000 years old (Diamond,1993:52).

slowed down differentiation, that Tasmanians are morphologically most similar to south eastern Australians and have diverged no more than expected if Tasmania had remained attached to the mainland (Pardoe 1991:1-3,9-15,18). Based on craniometric evidence, Howells concluded that Australians, Tasmanians and Melanesians (represented by New Britain) share the one basic morphological pattern, but within that, Tasmanians have greater affinity with New Britain than with Australians (Howells 1974:159).

A sample of Tasmanian crania, as distinct from mainland Australian crania, has been included in the study. However, the sample size is severely limited by the scarcity of adequately documented Tasmanian material in cranial collections. There are 2 main reasons accounting for the tendency to mislabel crania as "Tasmanian": (i) the movement of Australian aborigines from the mainland to Tasmania after European colonization (Wunderly & Wood-Jones 1933:584) and (ii) the acceptance of poorly documented "Tasmanian" material into collections in view of the high interest in and rarity of Tasmanian specimens (Wunderly 1939:330; Plomley 1962:3,1966:1; Howells 1989:96).

As well as the 7 Tasmanian crania from the Natural History Museum referred to in the description of the Australian sample, the Tasmanian sample consisted of 3 crania from the Institute of Biological Anthropology, Oxford, 1 from the University Museum Oxford, and 3 from the Duckworth Collection, Cambridge. "CRANID" (Wright 1990,1992) was used to help identify doubtful "Tasmanian" crania. Damage to 2 of the 3 crania from Cambridge and 1 from the NHM collection prevented measurement of a number of variables, thereby excluding these crania from the multivariate analyses, though they are included in univariate analyses.

NEW BRITAIN: New Britain has been inhabited by modern humans since at least 33 kyr BP when with New Guinea, New Ireland, Australia and Tasmania, it constituted the super-continent Sahul Land. Opinions differ as to the ancestry of the recent Melanesian inhabitants of New Britain and their affinity with Australians and Tasmanians (Howells 1976:641-648; Allen et.al.1988:707; Klein 1989:395; Pietrusewsky 1990:333). The entire sample of 50 New Britain crania used in this study was

taken from the Willey Collection, Cambridge.

GABON: The Sub-Saharan African sample of 50 crania is from a collection presented to the Natural History Museum by Du Chaillu in 1864 and 1880. The crania came from the West African Bantu-speaking N'Komi tribes in the Fernand Vaz River Region of Gabon who are said to be descendants of the north eastern Bantu (Crewdson-Benington 1912:292).

BUSHMEN (SAN): Bushmen have been the object of much scrutiny by anthropologists, though a definition of "Bushman" is less than clear. On morphological, craniometric, linguistic or genetic grounds differences with other African groups, except Hottentots, has been emphasised; their similarity to Tasmanians has been claimed (Kitson 1931:298,299; Rightmire 1970:169,191,192). Regarded by some as a remnant of old Africa, in the framework of a single African origin of modern humans and compared to other African peoples, Bushmen have been described as at least very close to the ancestral population of modern humans (Cavalli-Sforza 1991:76,77; Hedges et al.1991:738-739; Howells 1960:305-310). From genetic and archaeological evidence, Deacon considers that the Bushman offers an example of continuity in southern Africa without significant population replacement, their ancestors having evolved in isolation for possibly 100 kyr, and sees archaeological links with Klasies River materials (Deacon 1993:104,110,114).

As for Tasmanian crania, securely provenanced Bushman crania are rare in museum collections and authenticity of labelling is a problem (Kitson 1931:286; Howells 1989: 113,114). Consequently, the Bushman sample is small and drawn from 3 different collections at the Natural History Museum, Cambridge University and the University of Edinburgh. "CRANID" (Wright 1990, 1992) was used to help identify doubtful "Bushman" crania. 7 crania from each of the 3 collections form the study sample. Because its state of preservation precluded the taking of some measurements, one Cambridge cranium was excluded from the multivariate analyses but included in univariate analyses where possible.

POUNDBURY: The sample representing Europeans in this study consists of 50 Romano-British crania from the Natural History Museum collection of 4th.Century Late Roman Poundbury material (Farewell & Molleson 1993:xii).

CHINESE: The Chinese sample represents East Asians in this study and consists of 44 crania from the Natural History Museum and 6 from Cambridge University. It was not possible to form a sample based on a well-defined local population; origins of the crania are widespread.

ANDAMANESE: It is thought that until the establishment of a permanent European settlement in 1858, the people of the Andamanese Islands, like the Tasmanians, had a long period of isolation from the rest of the world; even the 9 or more Andamanese tribes remained separate from one another. Andamanese crania have been described as "most beautifully proportioned" and "remarkably and strikingly alike, not merely in size but in form also. They are all small, round, brachycephalic crania" (Brown 1922:10-14,106-113; Man 1883:70-72; Thesaurus Craniorum 1867:67,68; Catalogue cards 8.0207, 8.0405, Nat. Hist. Mus.). Suggested affinities include groups from Malaysia and the Philippines, Papuans, Tasmanians, Africans and Mongoloids (Man 1883:70,77; Coon 1962:4).

6 crania in the Andamanese sample are from Cambridge University, the remaining 44 from the Natural History Museum, London.

VEDDAH: The Veddah sample consists of 14 crania from the Natural History Museum and 4 from Cambridge University.
There are 3 groups of Veddah:

Forest and Cave. They remained genetically isolated until the end of the 19th. Century.

Village. Associated with Singhalese but no intermarrying until mid-19th. Century.

Coast. Large admixture of Tamil blood.

An attempt was made to confine the sample to crania in one of the first 2 categories but adequate information was not available in every case.

ESKIMO: It is a long held view that Eskimos have a Mongoloid appearance and ancestry (Furst & Hansen 1915:49,50; Oetteking 1931:447; Duckworth & Pain 1900:140). Morant (1937:20) regarded the Greenland Eskimo as linked to modern Chinese through the Chukchi people of the extreme northeast of Asia (Morant 1937:18-20). That Eskimos do have north east Asian roots is supported by blood, dental and linguistic evidence (Cavalli-Sforza 1991:75-77;Turner 1989:70,75,76).

Regardless of the controversial issue of when modern man first entered North America, based on archaeological evidence, Bandi places the origin of Eskimos between 15,000 and 10,000 years ago with the arrival of a Siberian Arctic-Mongoloid ancestral group (Klein 1989:389,389; Bandi 1964:157,176). From consideration of the origin of languages, Greenberg favours an even later arrival in North America of Eskimos-Aluet ancestors in the most recent of 3 migration waves from Asia, suggesting that Eskimos reached Greenland less than 5,000 years ago (Greenberg 1992:63-65).

Since the 18th.century, there has been contact of Greenland Eskimos with Europeans. Though distributed over an immense (mostly coastal) region, Eskimos are remarkably uniform in appearance. Their material culture attests to their harsh hunter-gather lifestyle since it is associated almost exclusively with the struggle for food and protection from the cold (Morant 1937:9; Bandi 1964:4-9,198,199).

The Eskimo sample comprises 46 crania from the Natural History Museum and 6 from Cambridge University. Except for 4 crania from the Canadian side of Baffin Bay near the entrance to Lancaster Sound, all Eskimo crania are from Greenland (Eastern Eskimos).

TIERRA DEL FUEGIAN: Fuegians, the most southerly people of the world, are said to have consisted of 3 well differentiated though closely related tribes, at least 2 of which (Ona and Yahgan) are represented in the sample. It has been suggested that isolation of Fuegians from the rest of South America arrested their cultural advancement. In this, parallels have been drawn with Indo-Oceanic peoples such as Tasmanian, southeastern Australians and Veddahs, as survivors/ preservers of an earlier, simple culture. Marked similarity in cranial morphology between early South Americans and early and modern

Australians has also been claimed. Do points of cultural similarity result from convergence, or reflect a common cultural ancestry and genetic derivation from a common (Asiatic) ancestral population? (Cooper 1917:2,54,223-228; Neves & Pucciarelli 1991:261,270).

Apart from such possibilities, Fuegians are included in this study for their contribution to the large end of the cranial size range and because of their simple life-style adapted to an extreme environment. The sample size is limited by the scarcity of Fuegian material and the presence of deformity in some crania. One cranium in the sample is from Cambridge University; the other 15 are from the Natural History Museum.

In addition to the 11 populations described above and used in the main univariate and multivariate analyses, 3 other recent modern human samples were used for 3 specific purposes.

SPITALFIELDS: From the Natural History Museum Collection of 17-19th Century Spitalfields (British) material, a sample of crania of known sex was used to test the effectiveness of a possible "race-independent" sex discriminant function (Uytterschaut 1986:243). Spitalfields crania themselves do not show strong cranial sexual dimorphism, less so than Poundbury (Molleson & Cox, 1993:23). The sample consists of 27 males and 27 females (Appendix Table A.4.5).

MULTIPOPULATION GROUP -- ADULTS: This sample, necessarily limited to crania which were longitudinally bisected, was assembled for the purpose of measuring a specific endocranial variable, internal petrous transverse angle. Insufficient bisected crania were available to permit between-groups analysis, so analysis of variation is confined to that observed in this mixed modern human sample of 15 crania from 7 populations (Appendix Table A.4.2).

MULTIPOPULATION GROUP -- JUVENILES: 29 Crania of estimated ages between 3-16 years formed a mixed sample drawn from 9 modern human populations to investigate the development of some temporal features in juveniles (Appendix Table A.4.3).

4.2 MEASUREMENT DEFINITIONS AND DESCRIPTIONS

4.2.1 INTRODUCTION

90 cranial measurements, temporal and non-temporal, were initially taken (Table 4.2.1). Most measurements are linear, but some angular and some calculated variables are also included. In the Appendix, relevant landmarks are listed in Table A.4.8, and the measurements in Table A.4.9, together with their codes, instrument and/or aids to measuring and source references for well known measurements. Also in the Appendix, the keys to instrument and source abbreviations are given in Tables A.4.6 and A.4.7 respectively, and formulae for calculated variables are recorded in Table A.4.10.

Based on the Martin-type Dioptrograph (Mollison-Munchen 1938:541), a viewing box was constructed to facilitate the measurement in the one basal or lateral plane of several base and lateral features (Fig.4.2.13). The original Dioptrograph sighting tube, with cross hairs, was used in conjunction with the viewing box to locate appropriate landmarks. Figs.4.2.1-14 illustrate the measurements; those which need to be defined also in words are described in the following Sections 4.2.2-5.

4.2.2 NORMA LATERALIS.

MPW = Mastoid process width, m_3-m_4 in Fig.4.2.2. The sliding caliper measured the maximum anterior-posterior width of the mastoid process parallel to the Frankfurt line and from the highest freestanding point on the posterior surface. Any tympanic attachment to the anterior side of the mastoid was not included in the measurement.

EDIAM = Diameter of the long axis of the external auditory meatus, y_1-y_2 in Fig.4.2.3. The inner cavity axis was used as guide, but the diameter measured with the sliding caliper was that of the inner diameter of the lateral tympanic rim.

TTHK = Thickness of the tympanic lateral rim, x_1-x_2 in Fig.4.2.2 & 3. The sliding caliper measured the maximum thickness of the anterior side of the tympanic rim.

The viewing box (Fig.4.2.13) was used to take the next 8 measurements; a single reference line was drawn on the acetate sheet. Each cranium was placed with left (or right) side

TABLE 4.2.1 MEASUREMENTS AND CODES

This table lists the 90 measurements initially taken on the crania of 11 modern human population samples. Measurements defined in this study are described in Sections 4.2.2-5. The sources of definitions for other measurements are listed in Appendix Table A.4.9. In the same table are listed the instrument(s) used to take each of the 90 measurements.

* derived variables, (L) left, (R) right, (Av) average of L & R.

CODE	TEMPORAL VARIABLE
ATANGS	Angle of tympanic plate anter.side(L)
ATANGR	Angle of tympanic plate anter.side(R)
BANT	Distance of basion, perpendicular & anterior to bitympanic line
EANG	Ext.Auditory Meatus angle, long axis
EDIAM	Ext.Auditory Meatus long axis diameter
ELANG	Ext.Auditory Meatus angle, lower side
EUANG	Ext.Auditory Meatus angle, upper side
FPOS*	Distance of foramen magnum centre perp. & post.to bitympanic line
GAP	Glenoid fossa ant./post. length (L)
GFA*	Glenoid fossa area (L)
GFD	Glenoid fossa depth (L)
GFIDX*	Glenoid fossa ant-post/med-lat.ratio(L
GL1	Glenoid fossa length 1 (L)
GL2	Glenoid fossa length 2 (L)
GL3	Glenoid fossa length 3 (L)
GFV*	Glenoid fossa volume (L)
GML	Glenoid fossa medial-lateral width (L)
MANG	Mastoid process axis angle (L)
MPD*	Mastoid process depth, transverse axis (Av)
MPDL	Mastoid process depth, trans.axis (L)
MPDR	Mastoid process depth, trans.axis (R)
MPL	Mastoid process length, long axis (L)
MPV*	Mastoid process volume (Av)
MPVL*	Mastoid process volume (L)
MPWAV*	Mastoid process width (Av)
MPW	Mastoid process width (L)
MPWR	Mastoid process width (R)
MSCANG*	Mastoid-suprameatal crest angle (L)
PANGS	Petrous pyramid axis sagittal angle(L
PANGSR	Petrous pyramid axis sagittal angle(R
PIANGT	Petrous internal transverse angle (L)
PIANGTR	Petrous internal transverse angle (R)
PPLAV*	Petrous pyramid length (Av)
PPL	Petrous pyramid length (L)
PPLR	Petrous pyramid length (R)
PTANG*	Petrous-tympanic axes angle (L)
PTANGR*	Petrous-tympanic axes angle (R)
SCANG	Suprameatal crest angle (L)
TANGS	Tympanic plate axes angle (L)
TANGSR	Tympanic plate axes angle (R)
TIND*	Tympanic plate lat. rim indent (Av)
TPH	Tympanic plate height (L)
TPL	Tympanic plate length (L)
TSQH	Temporal squamous height (L)
TTHK*	Tympanic plate lat.rim thickness (Av)
TTHKL	Tympanic plate lat.rim thickness (L)
TTHKR	Tympanic plate lat.rim thickness (R)

CODE	NON-TEMPORAL VARIABLE
ASB	Biasterionic breadth
AUB	Biauricular breadth
AUBEAM	Brdth. between suprameatal crests
BANG*	Base angle(staphylion-hormion-basion)
BBH	Basion-bregma height
BHO	Basion-hormion length
BIEAM	Breadth between L & R tympanic lateral rims
BV	Perpendicular distance from staphylion-opisthion line to basion
ENIN*	Endinion-inion separation
ENOP	Endinion-opisthion chord
FANG*	Foramen magnum angle (staphylion-basion-opisthion)
FMB	Foramen magnum width
FML	Foramen magnum length
FRA	Frontal (nasion-bregma) arc
FRC	Frontal (nasion-bregma) chord
GOL	Glabella-opisthocranion length
HOV	Perpendicular distance from staphylion-basion line to hormion
INOPC	Inion-opisthion chord
LINC	Lambda-inion chord
NLA*	Nasal aperture area
NBHX*	Nasal aperture breadth/height ratio
NLB	Nasal aperture breadth
NLH*	Nasal aperture height (Av)
NLHL	Nasal aperture height (L)
NLHR	Nasal aperture height (R)
NOL	Nasion-opisthocranion length
OCA	Occipital (lambda-opisthion) arc
OCC	Occipital (lambda-opisthion) chord
OCCOCA*	Occipital chord/arc ratio
OCNINA	Opisthocranion-inion arc
OCNINC	Opisthocranion-inion chord
OIX*	Lambda-opisthion/inion-opisthion chord ratio
PAA	Parietal (bregma-lambda) arc
PAC	Parietal (bregma-lambda) chord
SBC	Bisupramastoid crest breadth
SCBGOL*	Bisupramastoid crest brdth/ glabella-opisthocranion lgth.ratio
SCXCB*	Bisupramastoid crest brdth./max.biparietal brdth.ratio
SPB	Staphylion-basion length
SPHO	Staphylion-hormion length
SPOP	Staphylion-opisthion length
WCB	Minimum cranial breadth
XCB	Maximum biparietal breadth
ZYB	Bizygomatic breadth

uppermost and aligned so the reference line passed through orbitale and porion as the Frankfurt horizontal. The sighting tube with cross hairs was used to locate all other landmarks.

TSQH = Temporal squamous height, ts-p in Fig.4.2.2. A line was drawn through porion and at right angles to the Frankfurt horizontal. The sighting tube was used to locate and mark on the acetate the point where the line cut the temporal squamous suture. The distance from this point to porion was measured by the sliding caliper.

MPL = Mastoid process axis length, m_1-m_2 in Fig.4.2.2. The axis of the mastoid was estimated and a corresponding line drawn on the acetate. A sliding caliper measured along this length from the mastoid tip to the Frankfurt horizontal.

MANG = Mastoid process axis angle, M in Fig.4.2.2. The angle the line drawn for MPL made with the Frankfurt horizontal was measured with a protractor.

SCANG = Suprameatal crest angle, SC in Fig.4.2.2. The difficulty of taking this measurement varies depending on how pronounced, well-defined and straight is the suprameatal crest above porion. A line corresponding to the tangent to the suprameatal crest was drawn on the acetate and the angle this line made with the Frankfurt horizontal measured with the protractor.

MSCANG = Mastoid-suprameatal crest angle, MSC in Fig.4.2.2. This angle could be calculated from MANG and SCANG (Appendix Table A.4.10), or measured with protractor from the lines corresponding to mastoid axis and suprameatal crest.

EANG = Orientation of the central axis of the external auditory meatus, E_2 in Fig.4.2.3. Using the inner cavity as guide, the central axis of the EAM was drawn on the acetate and the angle made with the Frankfurt horizontal measured with a protractor.

ELANG = Orientation of the upper side of the EAM, E_3 in Fig.4.2.3. A line corresponding to the orientation of the upper wall of the inner cavity of the EAM was drawn on the acetate. The angle made with the Frankfurt horizontal was measured with a protractor. Of the 3 EAM angles, this was the one most often difficult to measure since the upper side was often curved.

EUANG = Orientation of the lower side of the EAM, E_1 in Fig.4.2.3. A line corresponding to the orientation of the

Figs.4.2.1-4 MEASUREMENTS IN NORMA LATERALIS

FH	FRANKFURT HORIZONTAL
n	nasion
g	glabella
br	bregma
l	lambda
ocn	opisthocranion
i	inion
e	endinion
o	opisthion
p	porion
b	basion
h	hormion
s	staphylion
ob	orbitale
n^br	Frontal arc
n-br	Frontal chord
br^l	Parietal arc
br-l	Parietal chord
l^o	Occipital arc
l-o	Occipital chord
l-in	Lambda-inion chord
b-br	Basion-bregma height
g-ocn	Cranial length
n-ocn	Nasion-opisthocranion length
i^ocn	Opisthocranion-inion arc
i-ocn	Opisthocranion-inion chord
p-ts	Temporal squamous height
m_1-m_2	Mastoid process length
m_3-m_4	Mastoid process width
M	Mastoid process angle
SC	Suprameatal crest angle
MSC	Mastoid-suprameatal crest angle
d_1-d_2	Glenoid fossa depth
x_1-x_2	Tympanic plate lateral rim thickness
y_1-y_2	Ext.Aud.Meatus diameter
E_1	EAM lower angle
E_2	EAM angle
E_3	EAM upper angle

Fig.4.2.1.MAJOR CHORDS

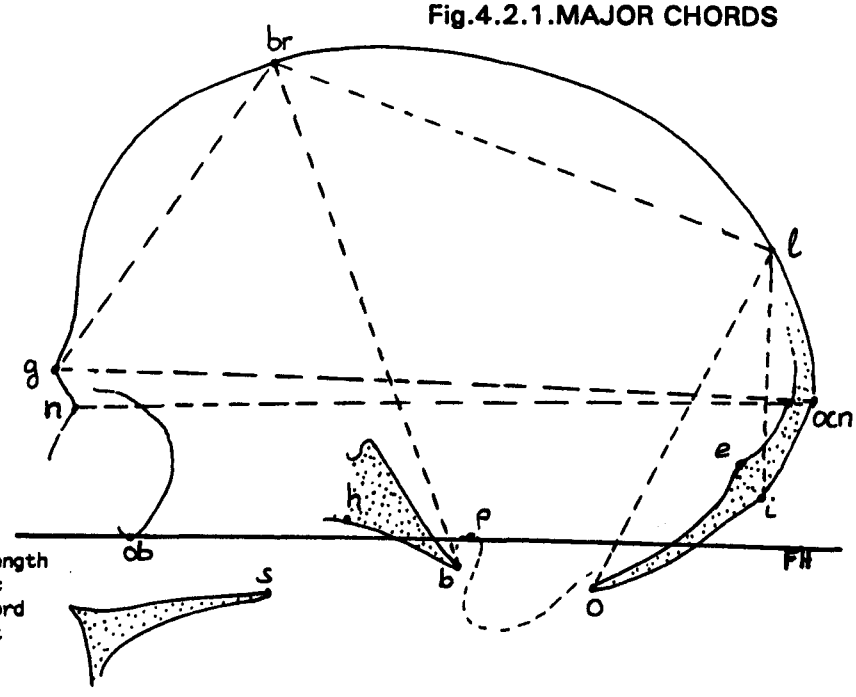


Fig.4.2.2. Left TEMPORAL REGION

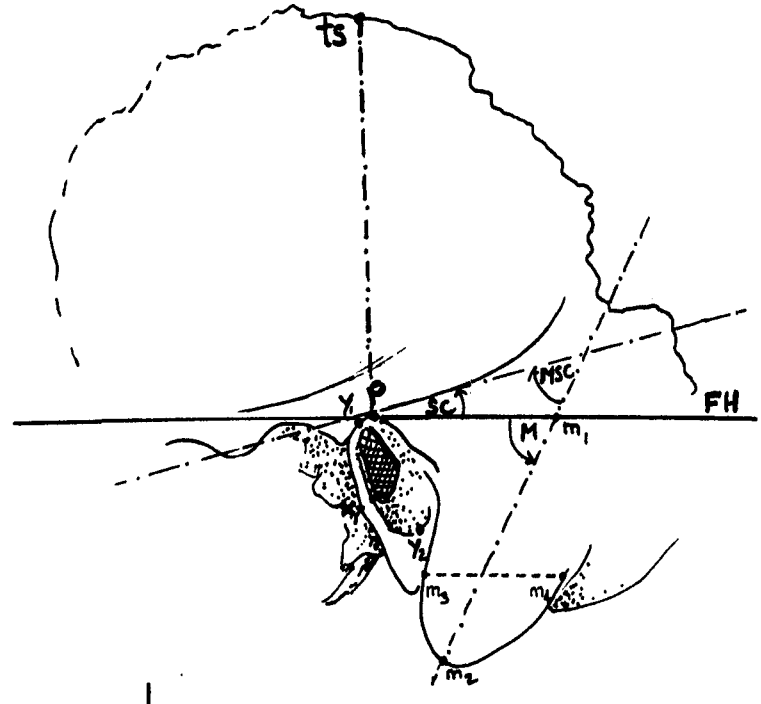


Fig.4.2.3. Left EAM ANGLES

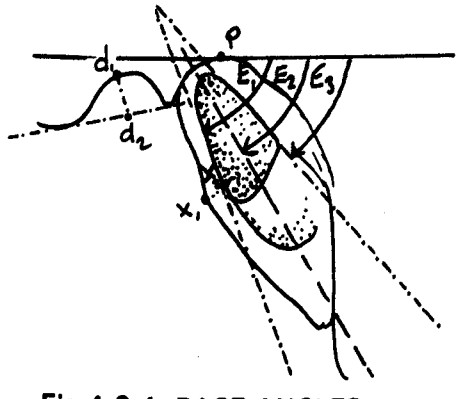
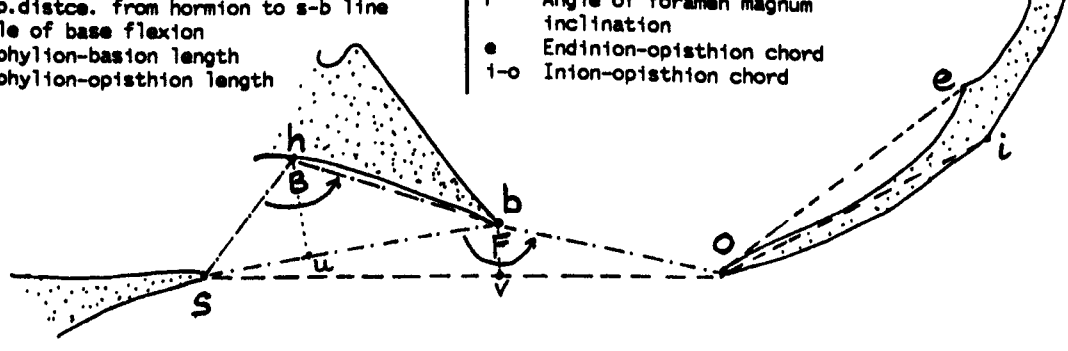


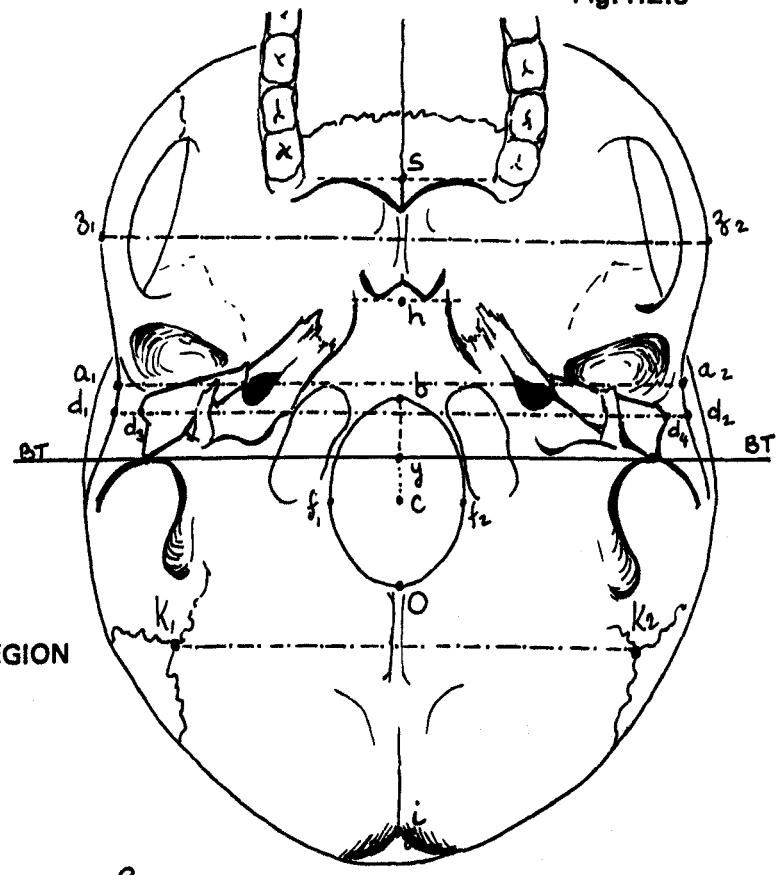
Fig.4.2.4. BASE ANGLES

s-h	Staphylion-hormion length
b-h	Basion-hormion length
h-u	Perp.distce. from hormion to s-b line
B	Angle of base flexion
s-b	Staphylion-basion length
s-o	Staphylion-opisthion length
b-o	Foramen magnum length
b-v	Perp.distance from basion to s-o line
F	Angle of foramen magnum inclination
e	Endinion-opisthion chord
i-o	Inion-opisthion chord



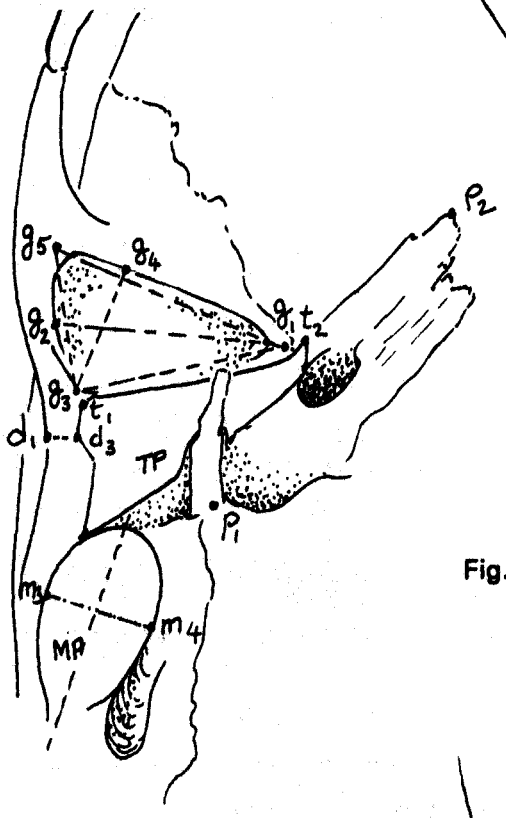
Figs.4.2.5-7 MEASUREMENTS IN NORMA BASALIS

Fig.4.2.5



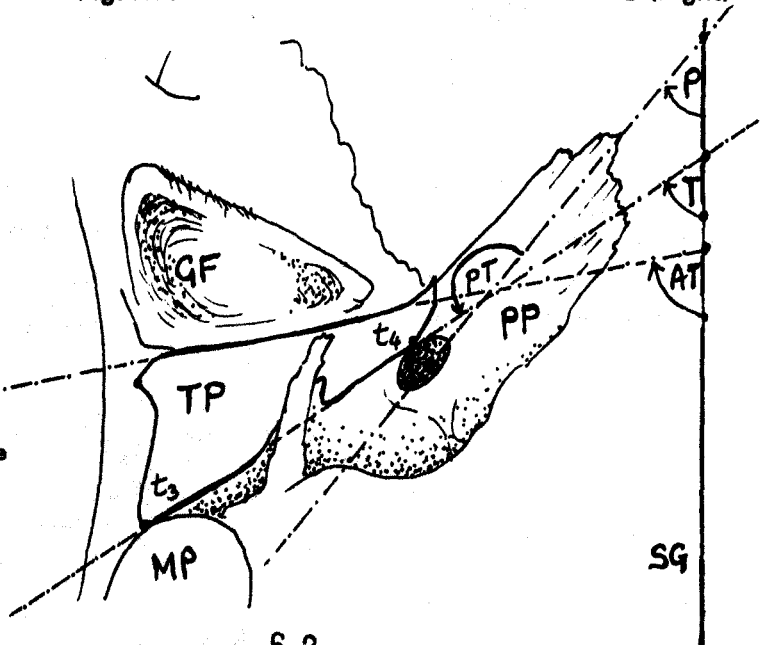
BT BITYMPANIC LINE
s-h Staphylion-hormion length
b-h Basion-hormion length
b-y Ant.perp.distance to basion from bitymp.line
c-y Post.perp.distance to foramen magnum centre from bitympanic line
o-i Opisthion-inion chord
b-o Foramen magnum length
f_1-f_2 Foramen magnum width
z_1-z_2 Bizygomatic breadth
a_1-a_2 Biauricular breadth
k_1-k_2 Biasterionic breadth
d_1-d_2 Breadth between pts. on L.& R. suprameatal crest cut by line through d_3 & d_4
d_3-d_4 Breadth between most lateral points on inferior rim of L.& R.tympanic plate

Fig.4.2.6. Right TYMPANIC REGION



d_1-d_3 Indent of lateral rim of tympanic plate lateral rim
t_1-t_2 Tympanic plate length
p_1-p_2 Petrous pyramid length
g_1-g_2 Glenoid fossa ant/post length
g_3-g_4 Glenoid fossa med/lat width
g_1-g_5 Glenoid fossa length 1
g_3-g_1 Glenoid fossa length 2
g_5-g_3 Glenoid fossa length 3
m_3-m_4 Mastoid process transverse depth

Fig.4.2.7. PETROUS & TYMPANIC ANGLES (Right)



TP Tympanic plate
PP Petrous pyramid
MP Mastoid process
GF Glenoid fossa
SG SAGITTAL LINE
P Petrous axis sagittal angle
T Tympanic axis sagittal angle
PT Petrous-tympanic axes angle
AT Tympanic ant.side sagittal angle
t_3-t_4 Tympanic ridge(lateral extreme to carotid canal)

lower wall of the inner cavity of the EAM was drawn on the acetate. The angle made with the Frankfurt horizontal was measured with a protractor.

4.2.3 NORMA BASALIS

PPL = Petrous pyramid length, p_1-p_2 in Fig.4.2.6. The sliding caliper measured the distance between the most anterior tip of the petrous pyramid to the base of the styloid process. The exact point at the base was taken as that point where the petrous axis met the medial side of the styloid base as tangent.

TPL = Tympanic plate length t_1-t_2 in Fig.4.2.6. The sliding caliper measured the distance between the anterior lateral rim of the tympanic plate and the medial-anterior end of the tympanic. For most crania the anterior point of meeting of the tympanic rim with the glenoid section of the temporal bone is well defined. But if this was not the case, the most lateral anterior point on the rim was taken as t_1. The size of the projection at the medial-anterior end varied considerably from negligible to a long and/or thick "processus supratubalis" (Weidenreich 1943:204). t_2 was taken as nearly as possible to the anterior point of the Eustachian tube exit.

GAP = Glenoid fossa anterior-posterior length, g_4-g_3 in Fig.4.2.6. The dial caliper measured the perpendicular distance from the anterior side of the glenoid process to the most inferior point on the postglenoid process.

GML = Glenoid fossa medial-lateral width, g_1-g_2 in Fig.4.2.6. The dial caliper measured the distance from the junction of the squamosal suture and the tympanosquamosal fissure to the estimated midpoint of the lateral side of the glenoid process.

GDL = Glenoid fossa depth, d_1-d_2 in Figs.4.2.3 & 12. A straight pencil line was lightly drawn from one side of the glenoid fossa to the other, from the most inferior point on the postglenoid process, through the most superior point on the roof and to the anterior articular surface. A cast of the glenoid fossa was obtained by using impression material, the inferior surface of which before setting was smoothed with a straight cylindrical metal rod to a plane which contained postglenoid process inferior point and the pencil mark on the

articular surface. Bisecting this cast along the transferred pencil line permitted the maximum depth of the glenoid fossa to be indirectly measured by the sliding caliper.

GFV = Glenoid fossa volume. This measurement is calculated from GAP, GML and GFD as defined in Appendix Table A.4.10. It is not an exact measure of volume but rather combines the 3 dimensions of glenoid fossa measurements as a means of comparing volume.

GFA = Glenoid fossa area was calculated from 3 glenoid fossa length measurements, GF1, GF2 and GF3, according to the formula in Appendix Table A.4.10. All 4 measurements are defined by Hinton & Carlson (1979:327).

TPH = Tympanic plate height, t_5–t_6 in Fig.4.2.8. Using the slide caliper, the distance between the most superior point along the Glaserian fissure to the most inferior point on the tympanic plate (ridge) medial to the styloid process, avoiding the (often erratic) vaginal process. It was necessary to use dividers on some crania for this measurement.

TIND = Average indent of the lateral rim of the tympanic plate, Fig.4.2.6. This distance, calculated from measurements, BIEAM and AUBEAM (Appendix Table A.4.10), measures how medially deep the external auditory meatus is positioned.

BIEAM = The breadth between the most lateral points on the anterior half of the inferior rim of the tympanic plate, d_3–d_4 in Fig.4.2.5. The large sliding caliper took this measurement.

AUBEAM = The breadth between the 2 points, d_1 and d_2, on the suprameatal crest where it is cut by the extension of the line through the 2 points d_3 and d_4 as defined for BIEAM, Fig.4.2.5. The large sliding caliper was used to take this measurement.

BANG = Flexion angle of the base, B in Fig.4.2.4. Three measurements were needed to calculate this angle from trigonometry as defined in Appendix Table A.4.10. The basion-hormion length (BHO) and the staphylion-hormion distance (SPHO), were measured using the sliding caliper. On a few crania it was necessary to use dividers to assist measuring SPHO. The perpendicular distance from the staphylion-basion chord to hormion, HV, was obtained using the coordinate caliper.

FANG = Angle of inclination of the foramen magnum, F in Fig.4.2.4. (The smaller the angle, the more forward rotated the foramen magnum). Three measurements were needed to

calculate this angle from trigonometry as defined in Appendix Table A.4.10. Foramen magnum length (FML) and staphylion-basion length (SPB) were measured using the sliding caliper. The coordinate caliper measured the perpendicular distance from the staphylion-opisthion chord to basion, BV.

The viewing box was used to take the next 7 measurements, the cranium placed base uppermost inside it (Fig.4.2.13). The sighting tube with cross hairs was used to draw the sagittal and bitympanic reference lines on the acetate sheet and locate all other landmarks.

BT = The bitympanic line, (Fig.4.2.5). This is the line through the conjunction of the anterior of the mastoid process and the posterior of the lateral rim of the tympanic plate. This is similar to, but not identical with the bitympanic line as defined by Dean & Wood (1981:64).

BANT = Anteriority of basion, b-y in Fig.4.2.5. Basion was marked on the acetate and the sliding caliper measured the perpendicular distance from the bitympanic line to basion.

FPOS = the perpendicular distance of the foramen magnum centre from the bitympanic line, calculated from BANT & FML as defined in Appendix Table A.4.10 and represented by y-c in Fig.4.2.5.

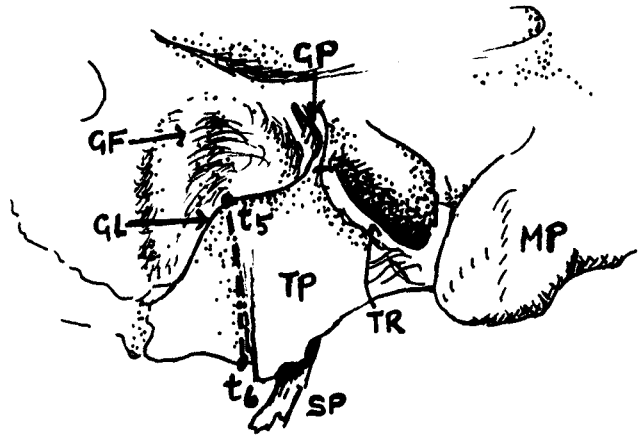
ATANGS = Sagittal angle of the anterior side of the tympanic plate, AT in Fig.4.2.7. With ruler placed along the anterior side of the tympanic, the angle it made with the sagittal line was measured with the protractor. (This method was found to be as accurate as drawing the relevant line before measuring).

TANGS = Sagittal angle of the tympanic plate axis, T in Fig.4.2.7. The tympanic crest was not always sufficiently straight or well-defined to use for the measurement. Instead, a line was defined from the most lateral posterior conjunction of the tympanic plate with the mastoid process, t_3, to the point of contact of the tympanic with the anterior side of the carotid canal, t_4. (This line often does correspond to the tympanic crest.) Ruler and protractor were used to measure the angle this line makes with the sagittal line.

PANGS = Sagittal angle of the petrous pyramid axis, P in Fig.4.2.7. A line was drawn on the acetate which best corresponded to the axis of the petrous pyramid; the angle it made with the sagittal line was measured with a protractor.

Fig.4.2.8. Left TYMPANIC PLATE (oblique aspect)

t_5-t_6 Tympanic plate height
MP Mastoid process
GF Glenoid fossa
GP Post glenoid process
GL Glaserian fissure
TP Tympanic plate
TR Tympanic plate lateral rim
SP Styloid process



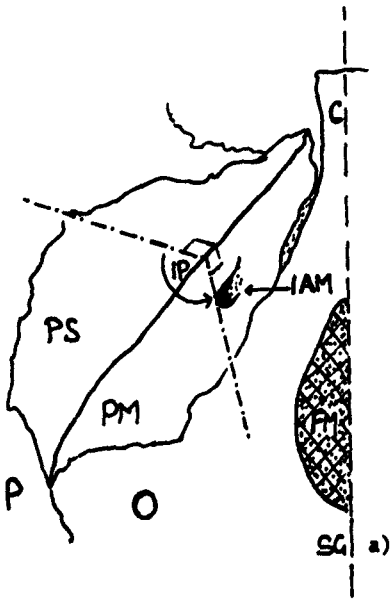


Fig.4.2.9 a & b. Left PETROUS BONE (oblique internal aspect)

IP Internal petrous angle
PS Petrous superior surface
PM Petrous medial surface
IAM Internal acoustic meatus
P Parietal
O Occipital
FM Foramen magnum
C Clivus
IM Impression material

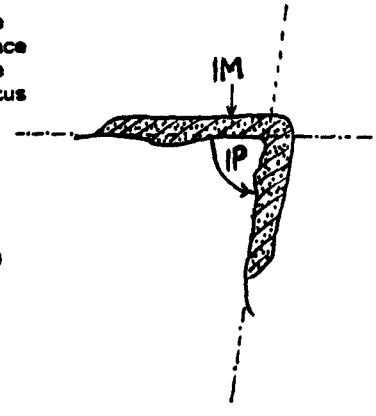


Fig.4.2.10. NORMA OCCIPITALIS

l Lambda
i Inion
x_3-x_4 Maximum parietal breadth
s_1-s_2 Bisupramastoid crest breadth
k_1-k_2 Biasterionic breadth

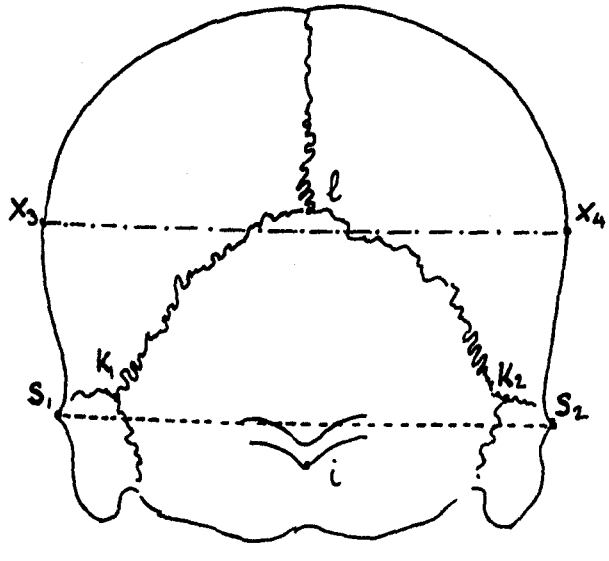


Fig.4.2.11. OCCIPITAL (Internal aspect)

e endinion
o opisthion
IOG Internal occipital groove
IOP Internal occipital protruberance
LSG Lateral sinus groove (L)
SSS Sup.sagittal sinus sulcus
CE Cerebrum fossa (R)
CL Cerebellum fossa (R)

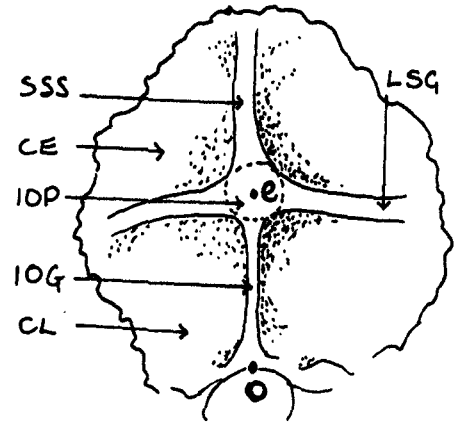
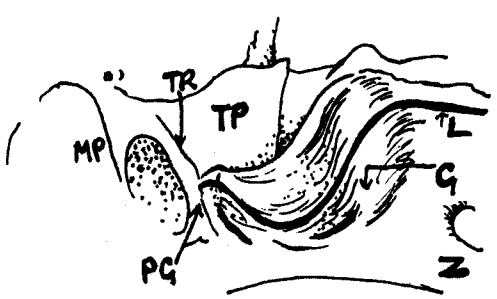


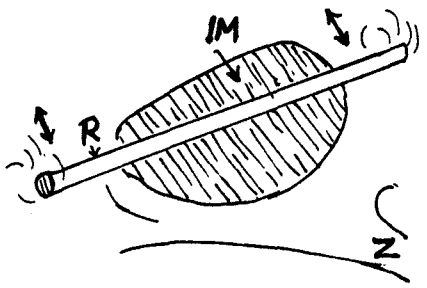
Fig.4.2.12. GLENOID FOSSA DEPTH (L)

a)
GF glenoid fossa
GP postglenoid process
L pencil line
MP mastoid process
TP tympanic plate
TR tympanic lateral rim
Z zygoma

b)
IM impression material
R metal rod

c)
X cross-section of cast
d_1-d_2 glenoid fossa depth





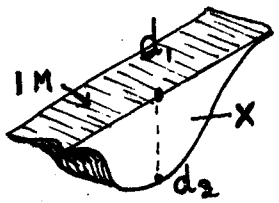
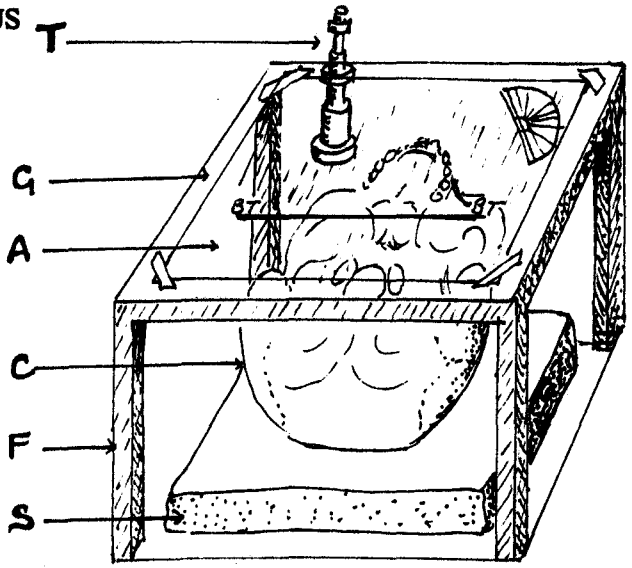


Fig.4.2.13. VIEWING BOX APPARATUS

T sighting tube
G glass plate
A acetate sheet
F wooden frame
C cranium
S foam support



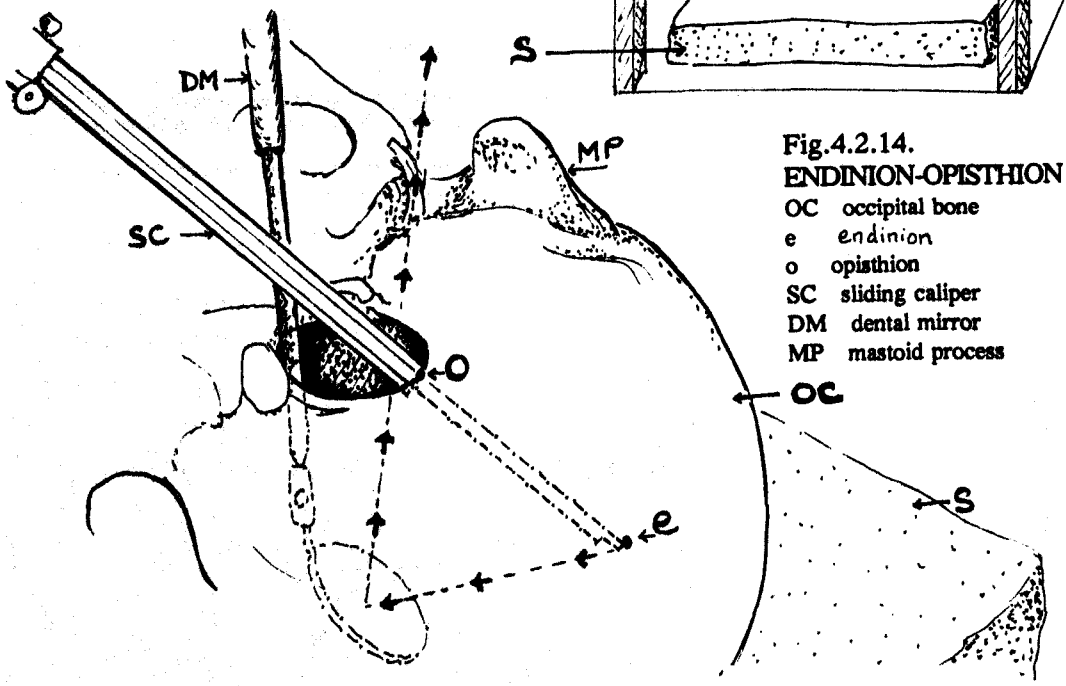


Fig.4.2.14.
ENDINION-OPISTHION CHORD

OC occipital bone
e endinion
o opisthion
SC sliding caliper
DM dental mirror
MP mastoid process

The difficulty of assessing the axis orientation varied with the petrous shape; often the grain of roughness in the anterior part of the petrous pyramid could be used as a guide.

PTANG = Angle between the petrous and tympanic axes, PT in Fig.4.2.7. This angle was calculated from PANGS and TANGS according to the formula in Appendix Table A.4.10.

4.2.4 NORMA OCCIPITALIS

SCB = Breadth between the most lateral extremities of the supramastoid crests as seen from norma occipitalis, Fig.4.2.10. The large sliding caliper was used.

4.2.5 INTERNAL MEASUREMENTS

ENOP = Opisthion-endinion chord, Figs.4.2.11 & 14. The dental mirror helped locate ENDINION (e), the centre point on the internal occipital protuberance. The central shaft of the sliding caliper measured the endinion to opisthion chord.

PIANGT = Internal petrous transverse angle. Fig.4.2.9 a & b. This measurement, involving petrous surfaces exposed in the endocranium, was necessarily restricted to cranium which had been bisected. A line was lightly pencilled in on the medial petrous surface, so that it was tangent to the posterior side of the internal acoustic meatus and perpendicular to the petrous spine (ridge along the superior petrosal sinus groove). Meeting this line and also perpendicular to the spine, a second pencil line was drawn on the superior petrous surface. A mould of the superior and medial surface of the petrous pyramid in the mid-region around the internal acoustic meatus was obtained using dental impression material. Bisecting the impression mould along the transferred pencil lines gave an outline of the transverse angle, which could then be measured using a protractor.

4.3 MEASUREMENT PRECISION ASSESSMENT

4.3.1 PRECISION ESTIMATION

"Precision is the closeness of repeated measurements"
(Sokal & Rohlf,1981:13).

From their investigation of measurement error in craniometry, using 72 measurements taken on 28 Eskimo crania, Utermohle and Zegura found the lack of intraobserver repeatability "disturbing", and the lack of interobserver reproducibility "alarming" (Utermohle & Zegura 1982:307,308). In another study, 2 investigators, Jamison and Zegura, independently took 16 measurements on 42 Eskimo crania and found that nearly perfect discrimination of the 2 sets of measurements on the same sample could be obtained on the basis of the variation contributed by the interobserver measurement error (Jamison & Zegura 1974:203). Consequently, in the interpretation of results from studies involving craniometric measurements, the authors stressed the importance of the inclusion of a measurement error analysis, and cautioned against incorporation of data from two or more investigators, particularly in studies involving multivariate analysis.

In this study of the temporal bone, all modern human craniometric measurements have been taken by one investigator. To assess the intraobserver reliability (precision) of the craniometric data, a number of methods of error estimation and a t-test were applied to replicated measurements.

DEFINITIONS

STANDARD DEVIATION OF DIFFERENCES: (Sokal & Rohlf 1981:51)

$$SD = \sqrt{\left(\sum_{i=1}^{n} d_i^2 / n\right)}$$

where SD is the standard variation of the differences between paired measurements,
d_i is the difference between paired measurements for case i,
n is the number of replicate pairs of measurements, (n=12).

The definitions and sources of the next 4 precision estimators are taken from a paper by Utermohle, Zegura and Heathcote (Utermohle et al.1983:94).

MEAN ABSOLUTE DIFFERENCE: (units = mm.)

$$MAD = \left(\sum_{i=1}^{n} |d_i|\right)/n.$$

PERCENTAGE ERROR: (units = %)

$$\%ERR = 100 \times \left[\sum_{i=1}^{n} (|d_i|)/n\right] / \left[(\bar{X}_2 + \bar{X}_1)/2\right]$$

where $\bar{X}_2$ and $\bar{X}_1$ are the 2 sample means.

TECHNICAL ERROR OF MEASUREMENT: (units = mm.)

$$TEM = \sqrt{\left(\sum_{i=1}^{n} d_i^2/2n\right)}$$

This estimator is sometimes referred to as "the method error" or "the standard error of a single determination" (Knapp 1992:235; Utermohle et al.1983:92).

COEFFICIENT OF VARIATION: (dimensionless)

$$CV = 100 \times \sqrt{\left[\sum_{i=1}^{n} (d_i^2)/2n)\right]} \; / [(\bar{X}_2 + \bar{X}_1)/2]$$

t-TEST VALUE & PROBABILITY:

$$t\text{-}VAL = \frac{(\bar{X}_2 - \bar{X}_1)}{(S_D \; / \; \sqrt{n})}$$

where $\bar{X}_2 - \bar{X}_1$ is the observed difference between the two means, S_D is the standard deviation of the differences of the paired observations. (Norusis, 1993a:258)

The significance level, p_t, is the probability that a difference at least as large as the t-VAL would occur if the means of paired measurements are really equal (Norusis 1993a:256).

In a comparative study of 11 measurement precision estimators, including the four defined above, Utermohle, Zegura and Heathcote found that on the basis of the Spearman rank-order correlation coefficients and complete linkage cluster analysis, the estimators group in 3 clusters (Utermohle et al.1983:91). %ERR and CV are in the cluster in which the members show strong association with mean measurement length; TEM and MAD are in a second cluster in which the members, having low correlation with mean measurement length, are comparatively unaffected by measurement size; and the t-test, indicating systematic error, is found in the third cluster which contributes the directional component, i.e. indicates whether the mean value of the first or second sample is larger.

4.3.2 PROCEDURE

To assess the precision of measurements in this study, a combination of estimators from the 3 clusters described by Utermohle et al. has been chosen to provide information about the magnitude of measurement error taking the measurement size into account (%ERR and CV), the precision of measurement regardless of measurement size (TEM) and the significance and directionality of measurement error (t-VAL and associated

probability).

Although the Mean Absolute Difference was calculated for each measurement pair, its inclusion together with TEM would be redundant. The 2 estimators are reported to be highly correlated (Spearman rank order correlation coefficient, r_s =.86; Utermohle et al.1983:94,91). TEM values have been recorded in preference to those of MAD, since TEM is an established error statistic, widely used in anthropological studies (Knapp 1992:235).

90 cranial measurements were taken from 12 crania randomly drawn from 4 population samples (4 Australian, 3 Andamanese, 3 Eskimo, and 2 Poundbury crania). Two additional measurements (left and right internal petrous transverse angles) were taken on 7 bisected crania. After a 3 month interval the 92 measurements were repeated. TEM, CV and %ERR values were calculated and the SPSS Paired Sample t-Test with 2-tailed probability was applied to the 2 sets of measurements. The significance level was taken as $p_t<.05$.

4.3.3 RESULTS

The sample means, standard deviation and four precision estimators for each variable are listed in Appendix Table A.4.11. Appendix Table A.4.12 lists the variables and associated estimator values in order of (i) p_t increasing magnitude, (ii) TEM decreasing magnitude, and (iii) %ERR decreasing magnitude. In the scatter plots involving precision estimator values, (Figs.4.3.1-10), it should be noted that the measurements and associated units are mixed (e.g. linear (mm), angular (degrees), ratios (no units)).

4.3.3.1 t-TEST (t-Value and probability):(Appendix Table A.4.12). 20 of the 92 paired measurements considered show a difference, significant at $p<.05$, between means in the 2 trials. 10 of these are derived measurements; of the 10 direct measurements, tympanic sagittal angle(R), mastoid process width(R) and glenoid fossa depth show a difference significant at $p<.01$; of the remaining 7, with difference significant at $p<.05$, 4 are temporal (mastoid process width(L), 2 glenoid fossa lengths, mastoid process depth), and 3 are non-temporal (nasal aperture height(L) and 2 components of base angle).

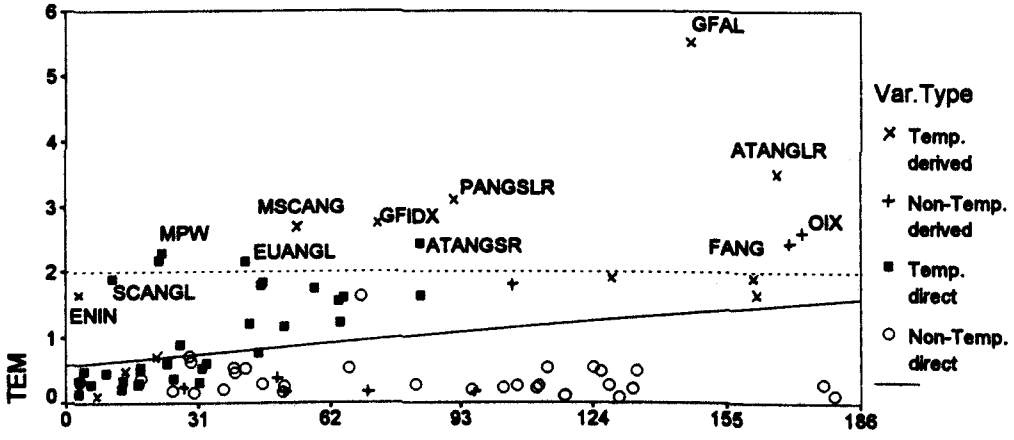
4.3.3.2 TECHNICAL ERROR OF MEASUREMENT: The calculation of TEM does not take into account the size of the measurement. Does the TEM value increase as the measurement magnitude increases? There is a significant positive correlation between TEM and the average magnitude of the pair of means for each measurement, but it is very weak ($r = .285$, $p = .007$).

In the plot of TEM against average mean (Fig.4.3.1), considering the non-temporal direct measurements only, TEM is not affected by increase in mean magnitude, suggesting that differences in TEM values depend on other factors such as difficulty in location of precise landmarks or inconsistency in interpretation and application of measurement definition. The only direct measurements with TEM values greater than 2.0 are the temporal variables of mastoid width (L & R), anterior tympanic angle (R), and upper EAM angle. This result and the comparatively large standard deviation values of these variables (Appendix Table A.4.11) are a true reflection of the difficulty experienced in precisely defining and repeating these measurements.

Of the direct measurements, temporal variables tend to have larger TEM values than non-temporal variables (Fig.4.3.2). The variables with the 7 highest TEM values are derived measurements (Appendix Table A.4.12), indicating compounding of errors from component measurements for those variables, (glenoid fossa area and ratio, mastoid-suprameatal crest angle, occipital index, foramen magnum angle, and combined L and R angles of the anterior tympanic and of the petrous axis). The unusual result for suprameatal crest angle (TEM =1.899, p_t =1.000) suggests considerable imprecision is involved in the measurement (as was found by experience) but the errors involved cancel by chance.

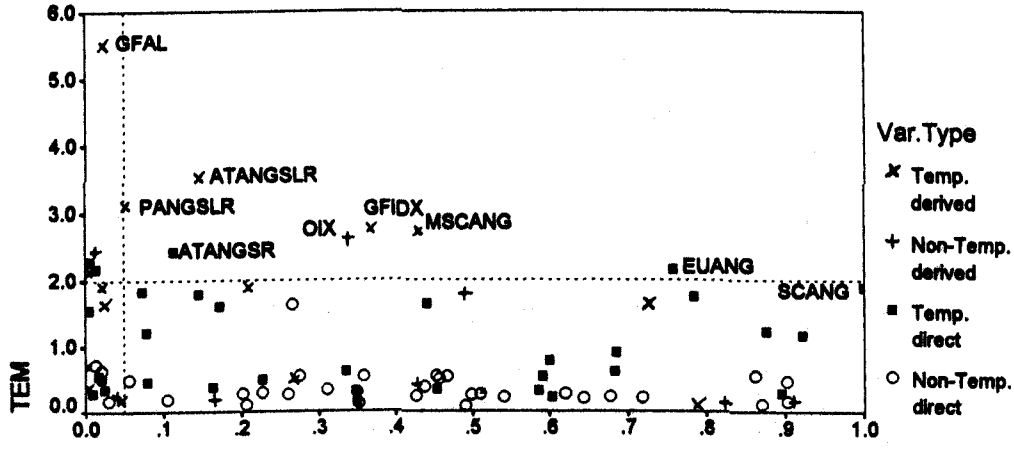
Considering the TEM values and t-Value probabilities together ($p < .1$, Fig.4.3.3), variables with the highest TEM values significant at $p < .05$ are the direct measurements mastoid process width(L,R) and tympanic sagittal angle(R) and indirect measurements glenoid fossa area, foramen magnum angle, mastoid width(av), tympanic angle(L+R) and endinion-inion separation. Also significant at $p < .05$ but with low TEM values (< 1.00), are the direct measurements glenoid fossa depth and 2 lengths, mastoid depth(R), 2 components of base angle and nasal aperture height(L), and indirect measurements,

Fig.4.3.1.Technical Error Measurement vs.Variable Mean



Variables represented by labelled coords. have high TEM values relative to measurement magnitude. TEM = .005 MEAN +.574; r =.285, p=.007.

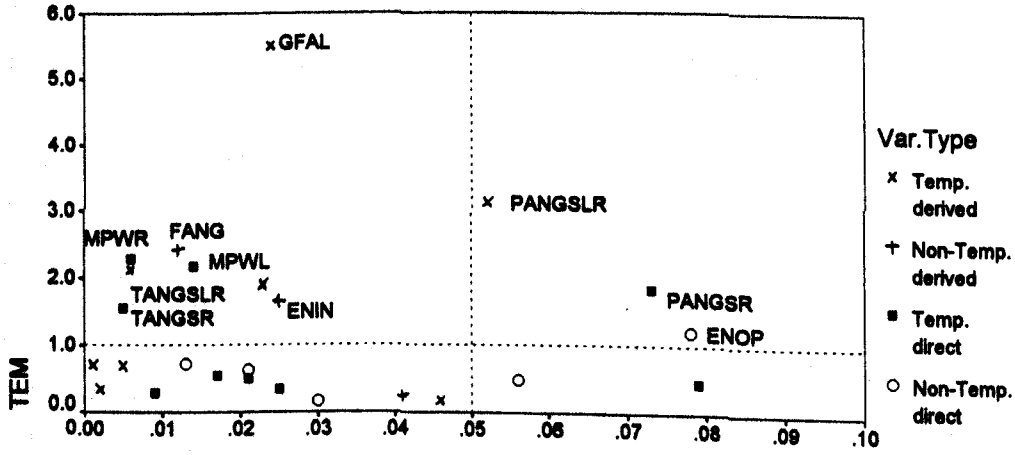
Fig. 4.3.2. TEM vs. t-Test Probability



TEM values tend to be smaller for Non-temp. than for Temp. measurements.

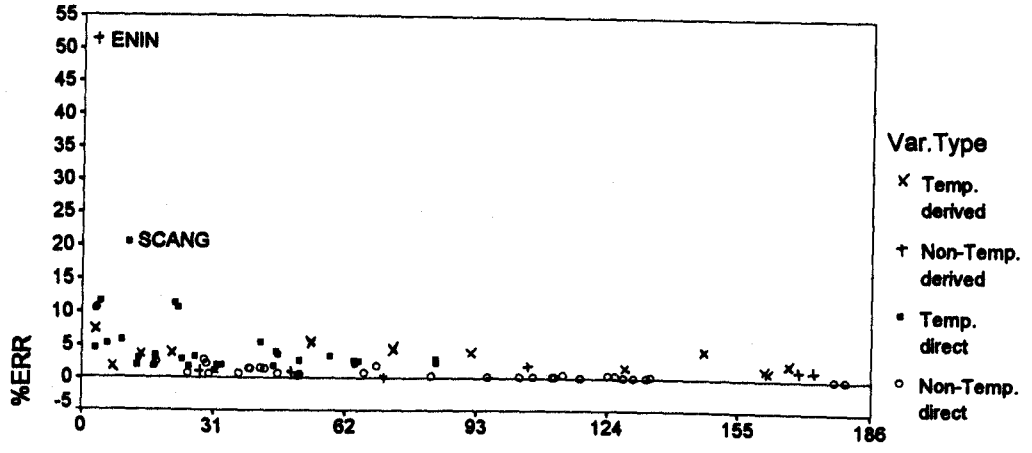
TEM values tend to be smaller for direct than for derived measurements.

Fig. 4.3.3. TEM vs. t-Test Probability



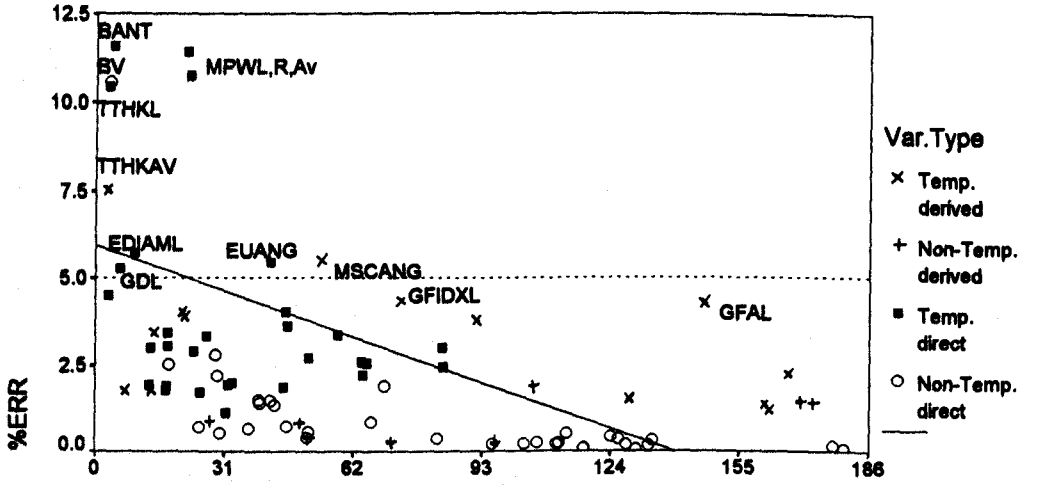
The only measurements with TEM>1.0, & p<.05 are mastoid width(L&R), tymp.seg.angle(R) -(direct);glenoid f.area & f. magnum angle -(indirect)

Fig.4.3.4. % Error vs. Variable Mean



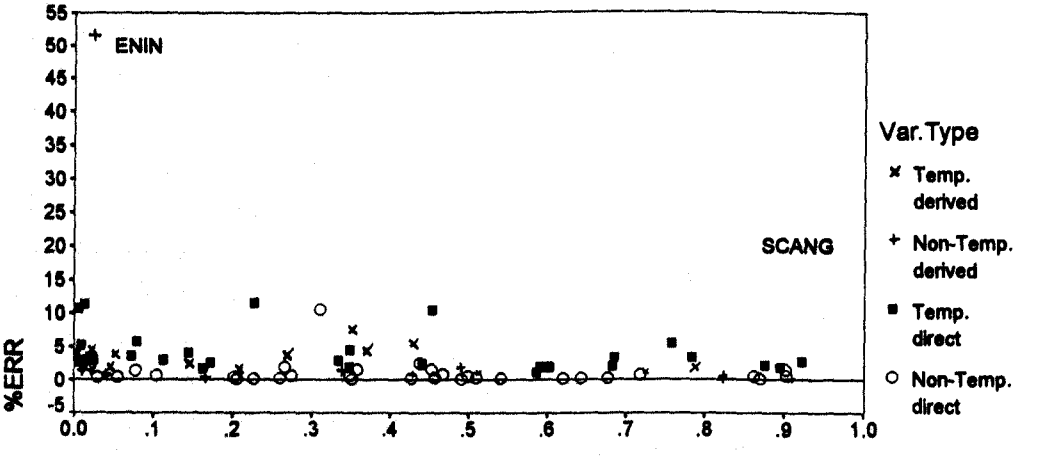
Endinion separation & s. crest angle have high % errors relative to the magnitude of their measurements.

Fig.4.3.5 % Error vs. Variable Mean



%ERR = .042Mean +5.94; r =-.348, p =.001.

Fig.4.3.6. % Error vs. t-Test Probability



At p<.05, the % error associated with endinion-inion separation is very large & significant; that of s.crest angle is large but not significant.

mastoid volume and av. depth, glenoid fossa volume and nasal aperture area. Two direct measurements, anterior tympanic angle(R) and upper EAM angle and 5 indirect measurements have comparatively high TEM values (TEM > 2.0) but these are not significant at p <.05 (Fig.4.3.2).

4.3.3.3 PERCENTAGE ERROR: Since the calculation of percentage error involves division by the average mean of the 2 samples, it does take into account the magnitude of the measurement. A negative, though weak correlation was found between percentage error and average mean (r =-.348, p =.001; Fig.4.3.5). Two measurements, suprameatal crest angle and endinion-inion separation, have particularly large percentage errors (Fig.4.3.4), but the comparatively small size of the measurements is an important contributing factor and is a good example of the systematic bias, as pointed out by Utermohle, Zegura & Heathcote, which estimators such as percentage error and coefficient of variation have against small measurements (Utermohle et al.1983:91).

Apart from these 2 extreme values, other (direct) measurements which have comparatively large percentage errors (> 5.0%) are tympanic plate lateral rim thickness, anteriority of basion, one component measurement of base angle, glenoid fossa depth, mastoid process width, EAM diameter, and upper EAM angle. These are small measurements, all but the last three particularly so (Appendix Table A.4.12 and Fig.4.3.5). Of the larger measurements, only derived measurements such as glenoid fossa area have percentage errors which are large relative to the size of the measurement.

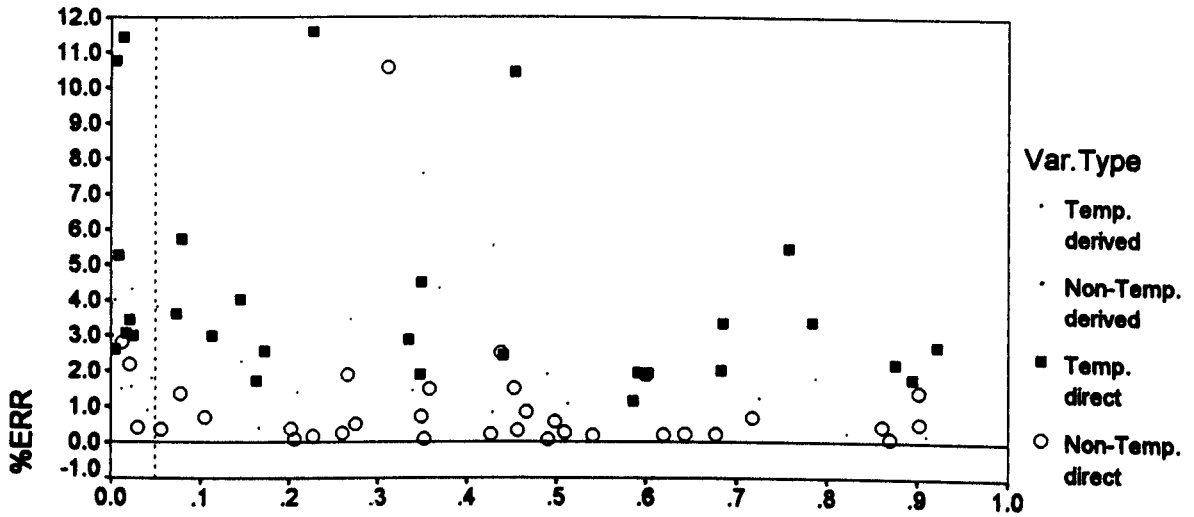
In the 3 plots of %ERR against t-Test probability

(i) Fig.4.3.6 shows the contrast between the extremely high and significant % error for endinion-inion separation (p<.05), and the very high but completely insignificant error for suprameatal crest;

(ii) Fig.4.3.7, with the scale adjusted to exclude the 2 extreme cases, shows clearly the tendency of temporal direct measurements to have higher % error values than non-temporal direct measurements.

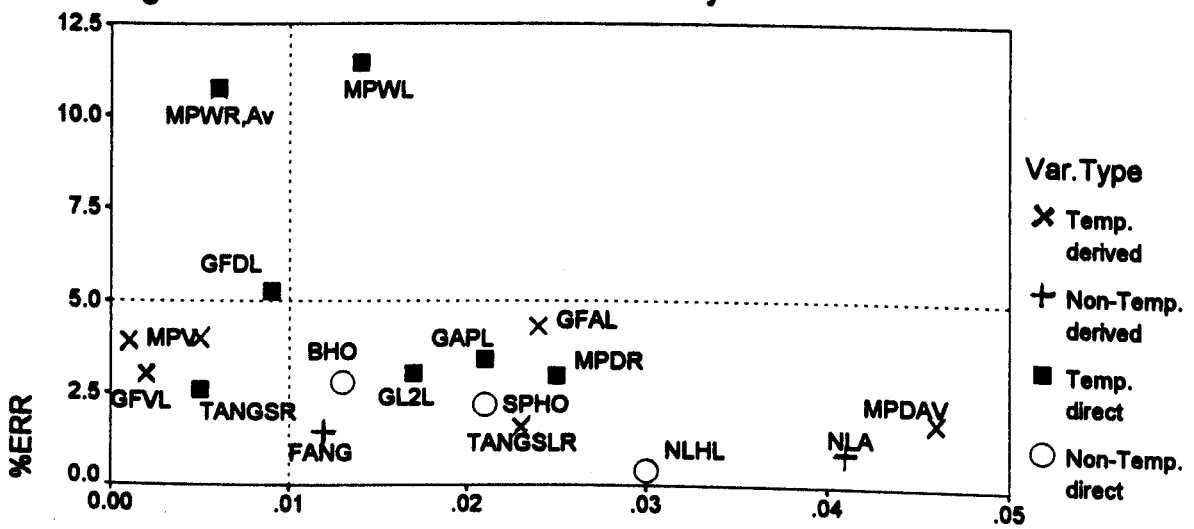
(iii) In Fig.4.3.8 the scale is adjusted to include only variables with differences significant at p <.05. The following (direct) measurements have % error >5% and

Fig.4.3.7. % Error vs. t-Test Probability



Direct temporal measurements tend to involve larger % error than do direct non-temporal measurements.

Fig.4.3.8. % Error vs. t-Test Probability



All variables represented are associated with % errors significant at $p < .05$. Mastoid width and g.fossa depth have the highest sig. % errors.

Fig.4.3.9. % Error vs. Technical Error of Measurement

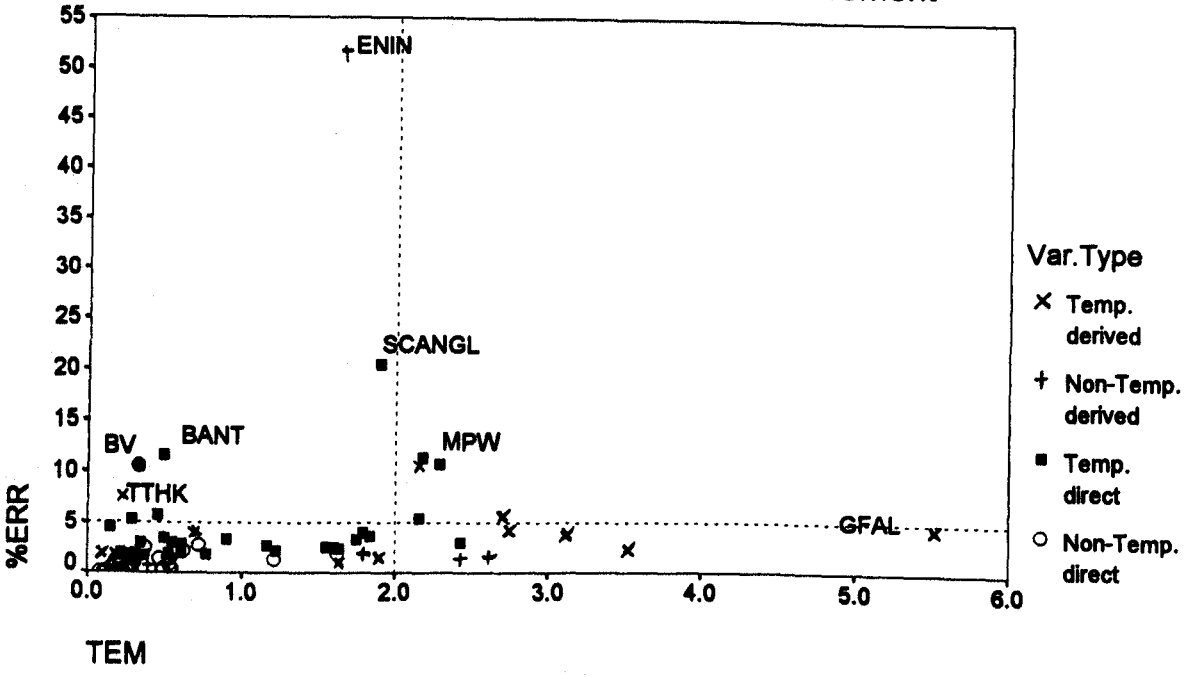
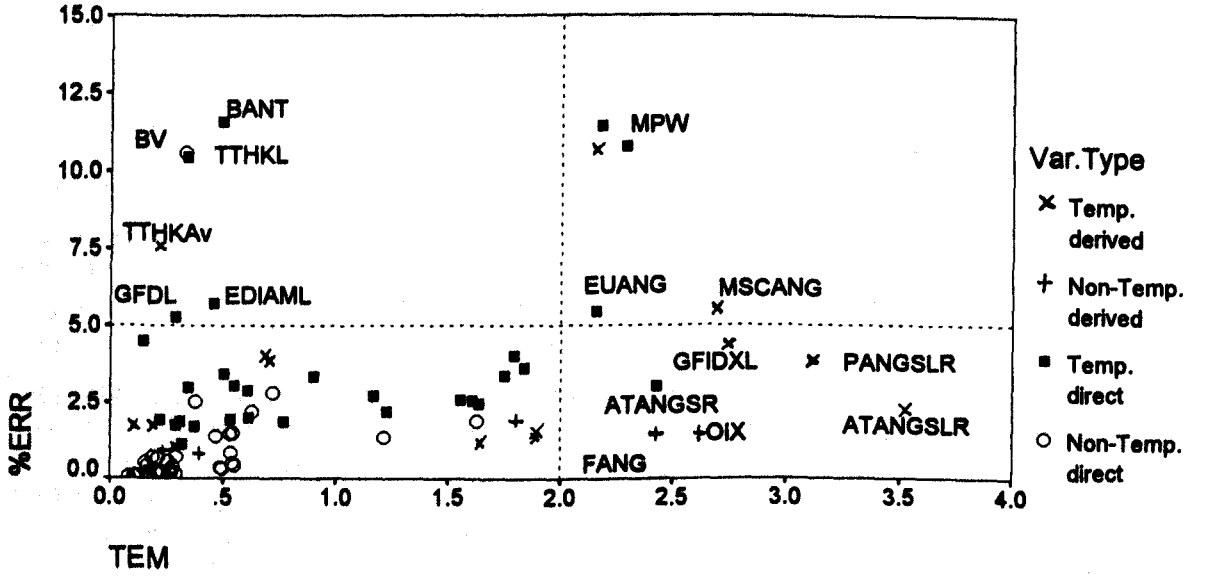


Fig. 4.3.10. % Error vs. Technical Error of Measurement



Mastoid width(L,R,Av), upper EAM angle and mastoid-s.crest angle have large values for both TEM and % Error estimators.

significant at p <.05:

endinion-inion separation (excluded from this plot), mastoid width(L,R) and glenoid fossa depth.

% Error values for the following measurements are between 2% and 5% and significant at p_t <.05:

mastoid depth(R), 2 glenoid fossa lengths, tympanic sagittal angle(R), a component of base angle (direct measurements); glenoid fossa area and volume, and mastoid volume (derived measurements).

4.3.3.4 TEM and % ERROR RELATIONSHIP: Figs.4.3.9 & 10 depict the relationship between Technical Error of Measurement and % Error. The extreme cases are seen clearly in Fig.4.3.9. Endinion-inion separation has a comparatively large TEM value, but being a very small (derived) measurement, the corresponding % error is extremely large. The same but less extreme pattern is true of suprameatal crest angle. Glenoid fossa area is a very large (derived) measurement with an extremely high TEM value (contributed to by 3 component lengths). However, it is also a very large measurement, so the corresponding % error is not particularly large.

Fig.4.3.10 is on a larger scale to show the smaller values more clearly. Mastoid width, upper EAM angle and mastoid-s.crest angle are medium sized measurements and have quite large values for both % error and TEM. Anteriority of basion, one component of the base angle, and tympanic rim thickness have small TEM values but they are particularly small measurements and the corresponding % errors are quite large. The same is true, but to less extent, of EAM diameter.

The 6 measurements which have large TEM values, but correspondingly small % errors (< 5%) are all large measurements and except for the tympanic sagittal angle (R), are derived.

4.3.3.5 COEFFICIENT OF VARIATION: As can be seen from the formula and from the CV and %ERR values in Appendix Table A.4.11, there is such close correspondence between the two estimators that a separate discussion of CV results is not necessary. The CV values are included for possible comparison with other studies as it is a frequently quoted precision estimator.

4.3.4 SUMMARY

From the results of analysis of 90 paired measurements taken on 12 crania, the following conclusions are reached concerning the precision of the measurements.

4.3.4.1 PRECISION ESTIMATOR TRENDS

[1] There is some tendency for the TEM values to be higher for temporal than for non-temporal measurements, suggesting that fewer temporal than non-temporal measurements are clearly defined and easy to measure.

[2] More noticeably, percentage error values tend to be higher for temporal than for non-temporal variables. But this also reflects the fact that in the study the temporal measurements tend to be smaller than the non-temporal.

[3] Technical Error of Measurement was found to have a weak positive correlation with measurement size; percentage error was found to have a weak negative correlation with measurement size.

4.3.4.2 EXCLUSION OR RETENTION OF VARIABLES

Retention of some variables and exclusion of others from further analysis was determined in the light of the precision assessment. A few variables will be retained despite showing low precision according to one or more of the estimators. Reasons are indicated in each case.

[4] EXCLUDED VARIABLES:

i) Variables with Means from the 2 trials Significantly Different at $p<.05$.

BHO	needed only to calculate variable BANG.
GL2	" " " " " GFA.
MPVL	redundant, highly correlated with MPVAV.

ii) Variables with No Significant Difference at $p<.05$ between Means in the 2 Trials: Despite this, these variables are excluded from further analysis because they were needed only to calculate other variables and/or they are redundant because highly correlated with another variable.

a) The following 4 variables have High %Err and CV

reflecting the difficulty in taking the measurement:

BV needed only to calculate variable FANG.

EDIAML landmarks even less precise on wider range of crania.

ELANGL, EUANGL both highly correlated with EANGL, larger errors than EANGL, needed only as practical help to locate EANGL.

b) These 11 Variables have Low %Err, CV and TEM

AUBEAM	needed only to calculate variable INDENT.
BIEAM	" " " " " "
GL1,GL2	" " " " " GFA.
HOV	" " " " " BANG.
NOL	redundant because highly correlated with GOL.
SPOP	" " " " " "
SPB	" " " " " "
FRC	" " " " " FRA.
PAC	" " " " " PAA.
OCNINC	" " " " " OCNINA.

[5] RETAINED VARIABLES:

i) Variables with No Significant Difference at $p<.05$ Between Means in the 2 Trials:

a) Small %Err, CV and TEM The most reliable measuremets.

Non-temporal Variables					Temporal Variables		
ASB	FMB	LINC	OCCOCA	SCBGOL	EANG	PLAV	TANGSL
AUB	FML	NBHX	OCNINA	SCXCB	GML	PLL	TIND
BANG	FRA	NLB	OIX	WCB	MANG	PLR	TPHL
BBH	GOL	NLHR	PAA	XCB	MPDL	PTANGL	TSQHL
ENOP	INOP	NLHAV	SCB	ZYB	MPL	PTANGR	

b) One or More Moderate to High Errors (%Err,CV or TEM). Although no significant bias was evident, these measurements are less precise than those in part a).

TPLL	TEM low, %ERR & CV moderately high.
ATANGSL,R	All errors (TEM, %ERR, & CV) moderate
ATANGLR	" " " " " " "
PIANGTL,R	All errors (TEM, %ERR, & CV) moderate to high
BANT	TEM low,%ERR & CV v.high because measurement small
FANT	" " " " " high, measurement small & derived
TTHKL,R,AV	" " " " " " " " " " " "
SCANGL	TEM low, %ERR & CV v.high, measurement quite small
MSCANGL	derived from 2 other variables, errors compounded
GFIDX	" " " " " " "

ii) Variables with Means from the 2 trials Significantly Different at $p<.05$. These variables are retained in view of their possible importance in the investigation, but with awareness that they are weak measurements. The magnitude of the errors involved varied for different variables, as indicated below:

a) Errors (%Err, CV and TEM) Not High.

NLA	derived from 3 variables, errors low & compounded
MPDR,AV	TEM low, %ERR & CV moderate, measurement small
SPHO	TEM low, %ERR & CV moderate
GFVL	" " " " " "
GAPL	" " " " " "
FANG	%ERR & CV low, TEM moderate, but measurement large and derived from 3 variables.

b) One or More High Errors (%Err, CV or TEM).

These 7 are the weakest of the variables retained; this will be kept in mind when the results of analyses are assessed.

GFAL	derived from 3 other variables, errors compounded
GFDL	TEM low, %ERR & CV high, because measurement small
MPVAV	TEM low, %ERR & CV high, derived from 3 variables
ENIN	TEM low, %ERR & CV v.high because measurement small and derived from 2 other variables
MPWL,R,AV	TEM high, %ERR & CV reflects imprecision of landmarks, but needed to convey overall size of mastoid process.

More variables are excluded as a result of the test in the next section for asymmetry in bilateral variables. A final variable list will be given at the end of that section.

4.4 BILATERAL ASYMMETRY

4.4.1 QUANTITATIVE ANALYSIS

31 of the variables (30 temporal and 1 non temporal) are bilateral. 5 of these variables are derived measurements. The purpose of this section is to determine if any of the bilateral temporal variables show significant asymmetry and to assess if it is feasible to analyze the variables using measurements from one side only.

4.4.1.1 PROCEDURE

Initially, left and right measurements for 30 of the 31 variables were taken on crania in the same sample which had been used to assess measurement precision (12 crania from 4 population samples). The one exception, petrous internal transverse angle, involved a different cranial sample, consisting of all 13 bisected crania on which this endocranial measurement could be made on both left and right petrous pyramids (Appendix Table A.4.3).

The student's t-test was applied to paired bilateral measurements for each variable, and the coefficient of variation between paired left and right measurements calculated. A t-value significant at $p < .05$ indicates a difference, inexplicable by chance, between left and right means for a particular variable; the sign of the t-value also indicates whether left or right measurement is larger (Allen & Pittenger 1991:82; Norusis 1993a:254; Tabachnick & Fidell 1989:38). The coefficient of variation indicates the size of the bilateral variation for a particular variable. Results of the t-test and coefficient of variation values are recorded in Appendix Table A.4.13, together with the means and standard deviation.

In the light of the outcome, verification of the results was attempted for 25 of the variables using a larger sample of crania. The results of the second t-test are also recorded in Appendix Table A.4.13.

4.4.1.2 RESULTS

Considering results from the largest samples used for each variable, 12 of the 31 variables show bilateral asymmetry significant at $p \leq .05$ (Appendix Table A.4.13 and Figs.4.4.1 & 2). How the magnitude of the asymmetry (as represented by CV values) varies with t-test probability for these 12 variables is depicted in Fig.4.4.1. Glenoid fossa area, tympanic rim thickness, EAM angle and mastoid depth show the largest bilateral variation (all have cv > 8.7).

The right PETROUS PYRAMID axis is inclined significantly more coronally (No.20).

The right PETROUS-TYMPANIC ANGLE (No.22) is significantly larger than the left.

The right TYMPANIC PLATE is significantly lower, its lateral rim significantly thicker, its axis significantly more sagitally inclined and its anterior side significantly more coronally oriented than the left (Nos.9, 7, 21 & 23). The greater thickness of the right tympanic rim was noted without explanation by Stewart in a study involving Greenland and Alaskan Eskimos and 2 Amerindian groups (Stewart 1933:488).

The right MASTOID PROCESS is significantly larger than the left in all dimensions (Nos.1-4, Table 4.4.1). The variation is greatest for the depth and least for the length.

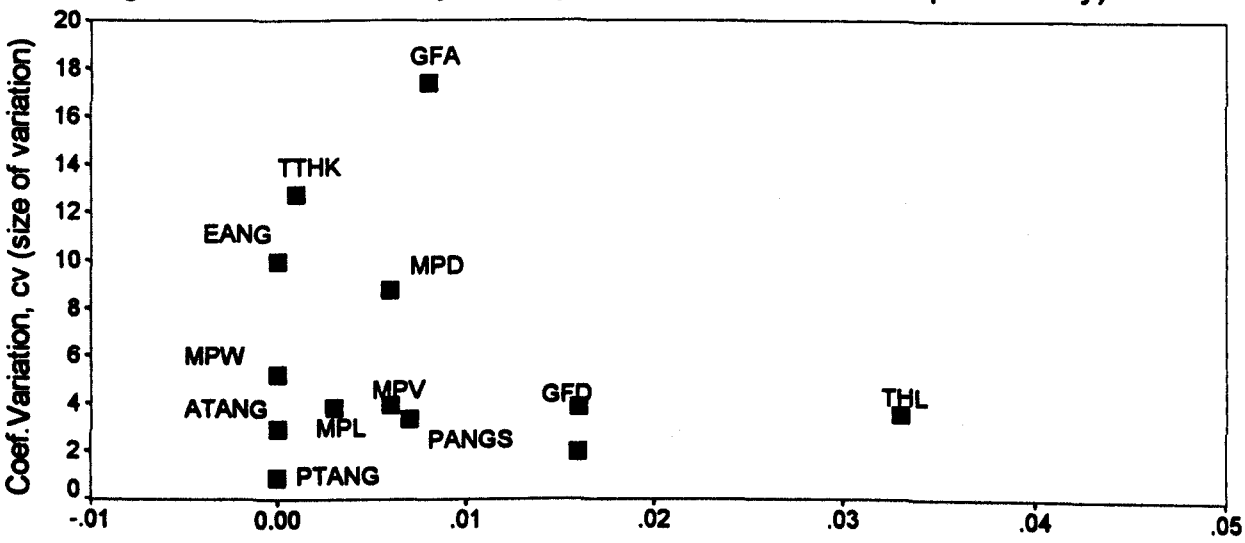
The right GLENOID FOSSA is significantly deeper and the area significantly smaller than the left (Nos.14 & 16). (Only the small sample, n=12, was tested for the area).

The right AXIS of the EXTERNAL AUDITORY MEATUS is inclined significantly more vertically than the left (No.30). The difference is large and the correlation between left and right measurements weak.

Of the 18 variables for which the difference between left and right means is not significant at $p < .05$, the largest bilateral variation occurs for suprameatal crest angle and upper EAM angle (Fig.4.4.2). This reflects possible fluctuating asymmetry and the difficulty experienced in taking these measurements, as is confirmed by the precision assessment results (Section 4.3.4.2).

For the only non-temporal feature considered, NASAL APERTURE HEIGHT, the bilateral difference in height means is

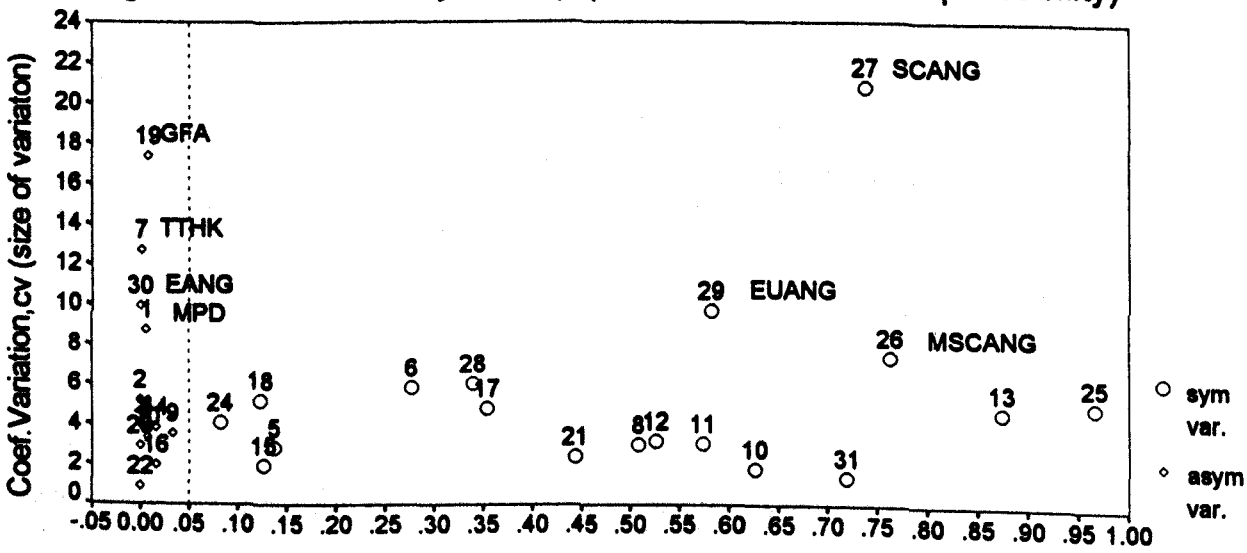
Fig.4.4.1. Bilateral Asymmetry(size of difference vs. probability)



The bilateral difference for all 12 variables is significant at p < .05

and greatest for G.F. area, T.P.thickness, EAM angle & Mastoid Depth.

Fig.4.4.2. Bilateral Asymmetry (size of difference vs. probability)

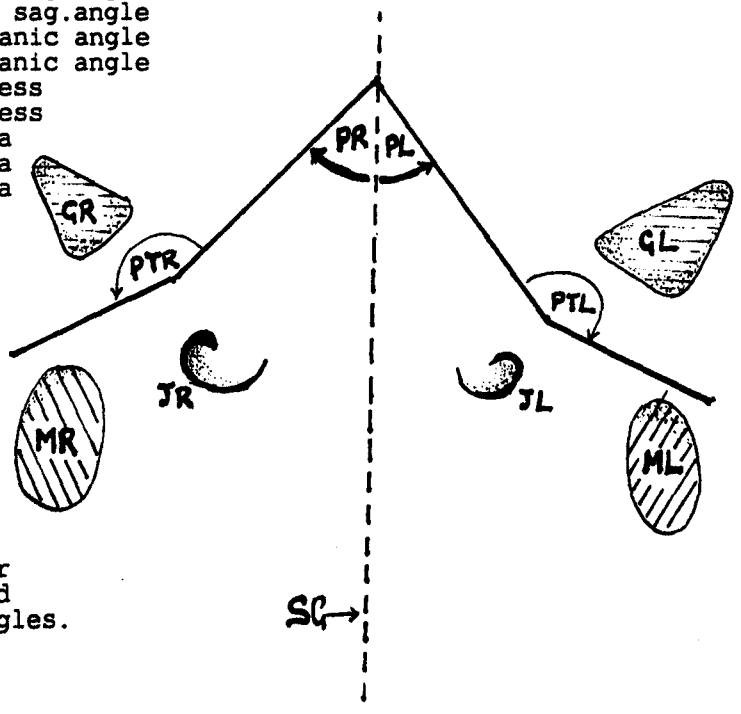


12 Vars. have bilateral asymmetry sig. at p<.05. SCANG's v.large differ-

ence in L&R means reflects fluctuating asymmetry & imprecise measurement

Fig.4.4.3 BILATERAL ASYMMETRY OF THE PETROUS & PETROUS-TYMPANIC ANGLES

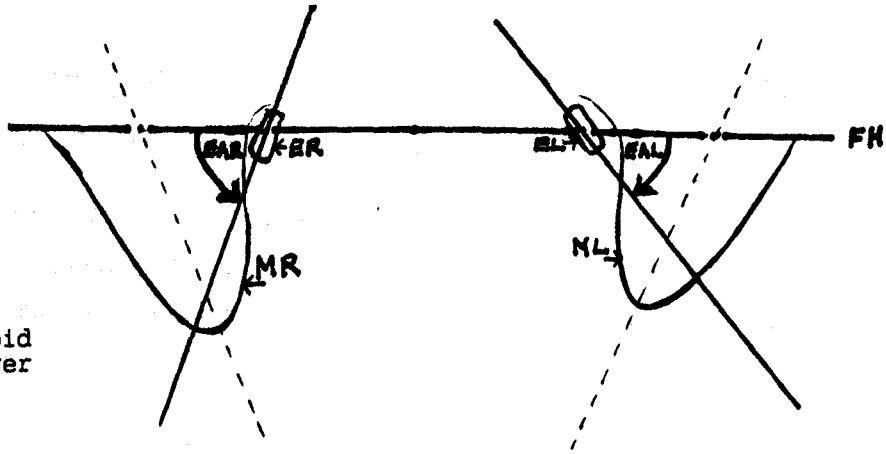
PR = Right petrous axis sag.angle
PL = Left petrous axis sag.angle
PTR= Right petrous-tympanic angle
PTL= Left petrous-tympanic angle
MR = Right mastoid process
ML = Left mastoid process
GR = Right glenoid fossa
GL = Left glenoid fossa
JR = Right jugular fossa
JL = Left jugular fossa
SG = Sagittal Axis



The left petrous pyramid axis is more sagitally inclined and the angle between the petrous and tympanic axes is more acute on the left. The larger right mastoid and larger area of the left glenoid fossa may affect the angles.

Fig.4.4.4 BILATERAL ASYMMETRY OF MASTOID SIZE & EXTERNAL AUDITORY MEATUS INCLINATION

FH = Frankfurt Horizontal
MR = Right mastoid process
ER = Right ext. auditory meatus
EAR= Right EAM axis angle
ML = Left mastoid process
EL = Left ext. auditory meatus
EAL= Left EAM axis angle



The right EAM axis is more vertically inclined than the left; the right mastoid process is larger than the left.

small and not significant at p <.05. If nasal aperture asymmetry does exist as reported (Hauser & De Stefano 1989:38) it is not evident in this variable.

4.4.1.3 DISCUSSION AND SUMMARY

ASYMMETRIC VARIABLES

(i) Asymmetry (significant difference in right and left means at p < .05) was found in the following features for which left-right pairs of measurements were considered for a sample of modern humans:

(a) Variables with larger values on the RIGHT side: Mastoid depth, length, width, volume; petrous sagittal angle; tympanic anterior sagittal angle; petrous-tympanic angle; tympanic rim thickness; external auditory meatus angle; glenoid fossa depth.

(b) Variables with larger values on the LEFT side: Glenoid fossa area; tympanic plate height and sagittal angle.

(ii) No significant difference at p < .05 was found in left and right means for the following bilateral variables:

temporal squamous height;	EAM diameter;
petrous pyramid length;	tympanic plate length;
g. fossa ant.-post.length;	g. fossa med.-lat.width;
g. fossa length/width ratio;	glenoid fossa volume;
mastoid process angle;	suprameatal crest angle;
mastoid-suprameatal crest angle;	nasal aperture height;
internal petrous trans. angle;	~~tympanic sagittal angle~~;
upper EAM angle;	lower EAM angle;

(iii) Correlation of left with right measurements is weak for these 4 variables: suprameatal crest angle, the 3 external auditory meatus angles. i.e. For these variables left and right measurements are likely to be subject to different influences.

POSSIBLE ASYMMETRY ASSOCIATIONS

Asymmetries in petrous, tympanic and petrous-tympanic angles are closely linked. A more coronally oriented right petrous axis and a more sagitally oriented right tympanic axis are consistent with the petrous-tympanic angle being larger on the right.

From spatial considerations, a compensatory association

may relate the thicker tympanic rim and larger mastoid process on the right side to the smaller right glenoid fossa area and the more coronally oriented anterior side of the right tympanic plate (Fig.4.4.3). Since no significant difference in glenoid fossa volume is found, this may indicate that the deeper right glenoid fossa compensates for a smaller right glenoid fossa area.

The more vertically oriented right external auditory meatus may also be related to the larger right mastoid process (Fig.4.4.4).

4.4.1.4 PRACTICAL CONCLUSIONS

In the remainder of the study, the LEFT measurements only are used, with 3 exceptions; the average of left and right measurements is used for mastoid process depth and nasal aperture height in order to match corresponding measurements defined by Howells ("MDB" and "NLH" respectively in Howells, 1973:174 & 177). The average of left and right measurements is also used for tympanic plate rim thickness, in view of the large bilateral variation and small absolute values.

The following variables have also been eliminated from further analysis for the reasons given:

Glenoid fossa lengths 1, 2, & 3. They were merely a means of calculating glenoid fossa area; glenoid fossa width and length are represented by 2 other variables, GML & GAP.

Upper and lower EAM angles. They were a practical guide to locating the central angle; these 3 variables are so highly correlated that inclusion of more than one is redundant.

A final list of variables is given in Table 4.4.1.

TABLE 4.4.1 REDUCED LIST OF VARIABLES

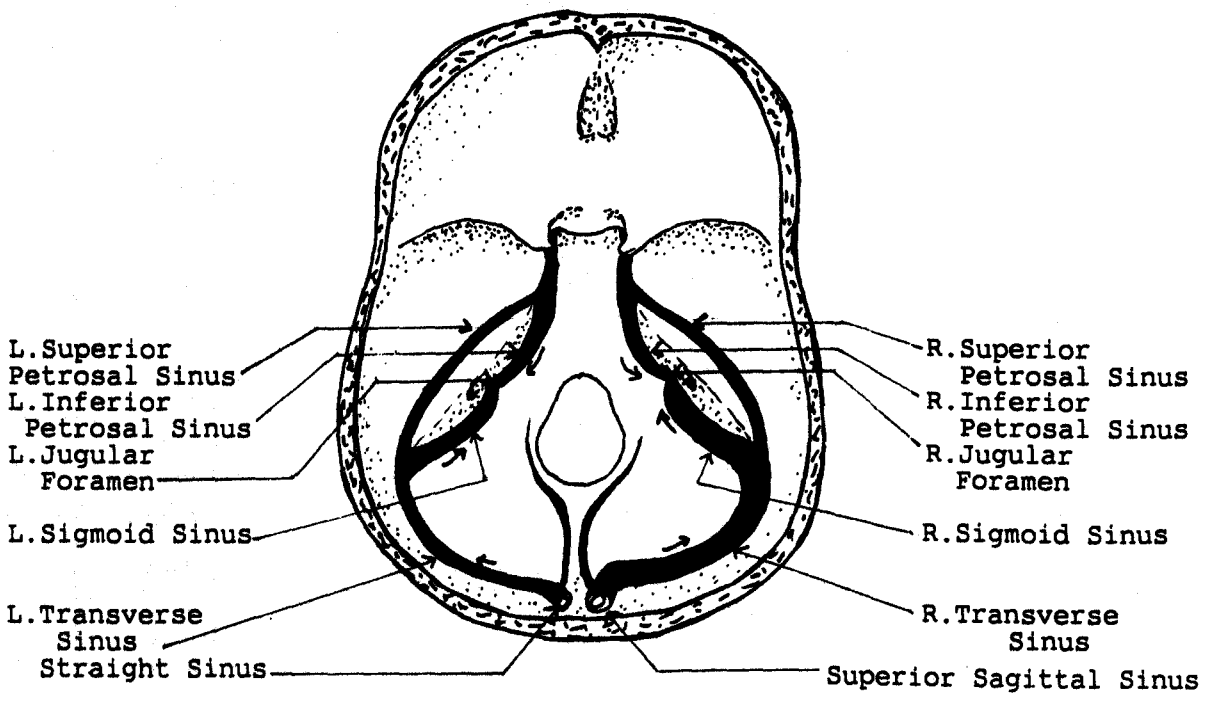
56 VARIABLES, (37 direct measurements and 19 derived* variables; 27 temporal and 29 non-temporal variables).

PREVIOUS CODE			VARIABLE NAME	REVISED CODE
1	ASB		BIASTERION BREADTH	ASB
2	ATANGSL		SAGITTAL ANGLE OF ANTERIOR SIDE OF TYMPANIC PLATE	ATANGS
5	AUB		BIAURICULAR BREADTH	AUB
7	BANG	*	BASE FLEXION ANGLE	BANG
8	BANT		BASION POSITION ANTERIOR TO BITYMPANIC LINE	BANT
9	BBH		CRANIAL (BASION-BREGMA) HEIGHT	BBH
13	EANGL		ANGLE OF EXTERNAL AUDITORY MEATUS CENTRAL AXIS (length)	EANG
16	ENIN	*	ENDINION-INION SEPARATION	ENIN
17	ENOP		ENDINION-OPISTHION CHORD	ENOP
19	FANG	*	ANGLE OF INCLINATION OF FORAMEN MAGNUM	FANG
20	FMB		FORAMEN MAGNUM WIDTH	FMB
21	FML		FORAMEN MAGNUM LENGTH	FML
22	FPOS	*	F.MAGNUM CENTRE POSITION POSTERIOR TO BITYMPANIC LINE	FPOS
23	FRA		FRONTAL ARC	FRA
25	GAPL		GLENOID FOSSA ANT.-POST. LENGTH (left)	GAP
26	GFAL	*	GLENOID FOSSA AREA (left)	GFA
27	GFDL		GLENOID FOSSA DEPTH (left)	GFD
28	GFIDXL	*	GLENOID FOSSA WIDTH/LENGTH RATIO (left)	GFIDX
32	GFVL	*	GLENOID FOSSA VOLUME (left)	GFV
33	GMLL		GLENOID FOSSA MED.-LAT. WIDTH (left)	GML
34	GOL		CRANIAL (GLABELLA-OPISTHOCRANION) LENGTH	GOL
36	INOPC		INION-OPISTHION CHORD	INOP
37	LINC		LAMBDA-INION CHORD	LINC
38	MANGL		MASTOID PROCESS AXIS ANGLE (left)	MANG
39	MPDAV	*	MASTOID PROCESS DEPTH (THICKNESS)(av.)	MPD
42	MPLL		MASTOID PROCESS AXIS LENGTH (left)	MPL
43	MPVAV	*	MASTOID PROCESS VOLUME (av.)	MPV
46	MPWL		MASTOID PROCESS WIDTH (left)	MPW
48	MSCANGL	*	MASTOID-SUPRAMEATAL CREST ANGLE (left)	MSCANG
49	NLA	*	NASAL APERTURE AREA	NLA
50	NBHX	*	NASAL APERTURE WIDTH/HEIGHT INDEX	NBHX
51	NLB		NASAL APERTURE WIDTH	NLB
52	NLHAV	*	NASAL APERTURE HEIGHT (av.)	NLH
56	OCA		OCCIPITAL ARC	OCA
57	OCC		OCCIPITAL CHORD	OCC
58	OCNINA		OPISTHOCRANION-INION ARC	OCNINA
60	OIX	*	OCCIPITAL (LAMBDA-INION/INION-OPISTHION) INDEX	OIX
61	PAA		PARIETAL ARC	PAA
63	PANGSL		PETROUS PYRAMID SAGITTAL ANGLE (left)	PANGS
67	PPLL		PETROUS PYRAMID LENGTH (left)	PPL
69	PTANGL	*	PETROUS-TYMPANIC ANGLE (left)	PTANG
71	SCANGL		SUPRAMEATAL CREST ANGLE (left)	SCANG
72	SCB		BISUPRAMASTOID CREST BREADTH	SCB
73	SCBGOL	*	CRANIAL BREADTH/LENGTH RATIO	SCBGOL
74	SCBXCB	*	CRANIAL BIS'MASTOID CREST/MAX.PARIETAL BREADTH RATIO	SCXCB
76	SPHO		STAPHYLION-HORMION LENGTH	SPHO
78	TANGSL		TYMPANIC PLATE AXIS SAGITTAL ANGLE (left)	TANGS
71	TIND	*	INDENT OF TYMPANIC PLATE RIM (av.)	TIND
82	TPHL		TYMPANIC PLATE HEIGHT (left)	TPH
83	TPLL		TYMPANIC PLATE AXIS LENGTH (left)	TPL
84	TSQHL		TEMPORAL SQUAMOUS HEIGHT (left)	TSQH
85	TTHKAV	*	TYMPANIC PLATE LATERAL RIM THICKNESS (av.)	TTHK
88	WCB		MINIMUM CRANIAL BREADTH	WCB
89	XCB		MAXIMUM BIPARIETAL BREADTH	XCB
90	ZYB		BIZYGOMATIC BREADTH	ZYB
---	---	---	---	---
91	PIANGTL		PETROUS PYRAMID INTERNAL TRANSVERSE ANGLE (left)	PIANGT

TABLE.4.4.2 JUGULAR FOSSA SIZE ASYMMETRY

	AND	GAB	AUS	CHI	ESK	TOTAL
R>L	71.4%	69.4%	76.9%	81.8%	70.0%	74.3%
R=L	26.2%	19.4%	13.5%	9.1%	10.0%	15.4%
L>R	2.4%	11.1%	9.6%	9.1%	20.0%	10.3%
SAMPLE SIZE	42	36	52	44	40	214

Fig.4.4.5 BILATERAL ASYMMETRY OF THE SIGMOID & TRANSVERSE SINUSES: Superior Endocranial View



The right transverse (lateral) sinus is usually considerably larger than the left since it receives blood from the large superior sagittal sinus, whereas the left transverse sinus is continuous with the smaller straight sinus. The right sigmoid sinus, formed from the combined right transverse and superior petrous sinuses, is thus larger than the left. The sigmoid sinus joins the inferior petrous sinus to leave the cranial cavity via the jugular foramen as the internal jugular vein. The right internal jugular vein is usually larger than the left. The superior part of the internal jugular vein, the jugular bulb, is lodged in the jugular fossa, which also is usually larger on the right side than the left (Aiello & Dean 1990:169,170-172; Frazer 1920:196; Gray 1993:421,425,426).

4.4.2 DESCRIPTIVE ANALYSIS

4.4.2.1 SIGMOID SULCUS, JUGULAR FOSSA AND ASYMMETRY.

While taking the basal temporal measurements, the sometimes striking asymmetry of jugular fossae was noted. The probable interconnection of some of the asymmetries which was evident from the quantitative analysis results prompted an extension of the investigation to include a qualitative assessment of the jugular fossa asymmetry. Clarification of the relationship of the jugular fossa to the sigmoid sulcus was also sought from the literature.

The sigmoid sulcus, a large endocranial groove containing the sigmoid sinus, passes directly behind the mastoid antrum and contributes to the volume of the posterior part of the mastoid process (Section 3.1.2, Fig.3.1.3 in anatomy section). Hence the sigmoid sinus asymmetry is likely to contribute to the same temporal variable asymmetries as mastoid size asymmetry.

In modern humans, the right jugular fossa as well as the right sigmoid sulcus are reported to be larger than on the left (Gray 1989:359,365; Hauser & De Stefano 1989:133; Krogman 1932:410). Weidenreich observed the same tendency in *H.erectus* (Weidenreich 1943:68,1951:279) and also noted that the size of both jugular fossa and sigmoid sulcus increase from anthropoids to *H.erectus* to modern humans (Weidenreich 1943:61,206; evident in photo of Ngandong 7, Plate 8.8b). Since the petrous sagittal and petrous-tympanic angles are also known to increase from anthropoids to *H.erectus* to modern humans (Aiello & Dean 1990:69-71) it seems likely that asymmetry in jugular fossa size may have bearing on asymmetry in the orientation of the petrous axis and the size of the petrous-tympanic angle.

The purpose of this analysis is to quantify jugular fossa asymmetry and consider its probable relationship to external basal temporal asymmetry.

4.4.2.2 PROCEDURE

On 214 crania from 5 population samples (Andamanese, Gabon, Australian Chinese and Eskimo), the relative size of left and right jugular fossae was judged by inspection from norma basalis to correspond to one of 3 categories:

(i) Right obviously larger than left;

(ii) Left obviously larger than right;

(iii) Difference uncertain without measurement.

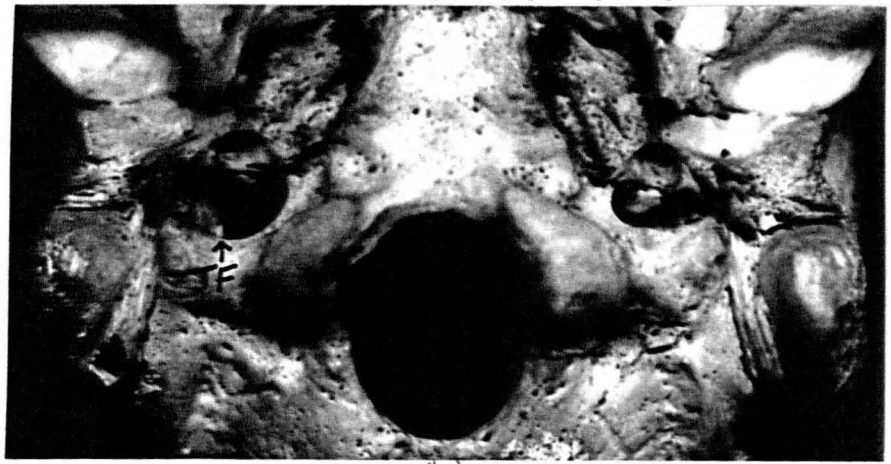
4.4.2.3 RESULTS

The results (Table 4.4.2) show that the right jugular fossa is larger than the left for at least 69.4% of crania in every population sample, and for at least 74.3% in the total sample. The left jugular fossa is judged to be larger than the right for only 10.3% of the total sample, and 15.4% of cases are undecided. A study by Di Chiro et al. reported 65.6% incidence of right side larger than left in modern humans (in Hauser & De Stefano 1989:133). For Australians, this study found the right jugular fossa is larger than the left 8 times more than the left is larger than the right. Krogman found a somewhat less marked frequency with right larger than left 5 times more than the reverse (Krogman 1932:410).

Evidence that the jugular fossa asymmetry does affect the relative positioning of surrounding structures is seen in the transverse orientation of the mastoid process axis as viewed from norma basalis. If the right jugular fossa is noticeably larger than the left, it was observed that the right mastoid process is often correspondingly aligned less coronally than the left. This is illustrated in the photos and diagrams in Plate 4.1a. The fact that the opposite asymmetry in mastoid alignment is evident in (rarer) cases of the left jugular fossa being noticeably larger than the right (Plate 8.8b), supports the idea that the asymmetry in mastoid alignment is a response to jugular fossa asymmetry. Also, from spatial considerations, the larger right jugular fossa is likely to be related to the more sagitally inclined right tympanic axis, the more coronally inclined petrous axis and the larger right petrous-tympanic angle.

Plate 4.1 ASYMMETRIES ASSOCIATED WITH THE JUGULAR FOSSA

a) When the right jugular fossa is larger than the left, the tympanic axis, the ant. side of the tympanic plate and the mastoid axis in basal view are more sagitally inclined on the right side, the right petrous axis is more coronally oriented than the left and the R. petrous-tympanic angle is larger than the left.



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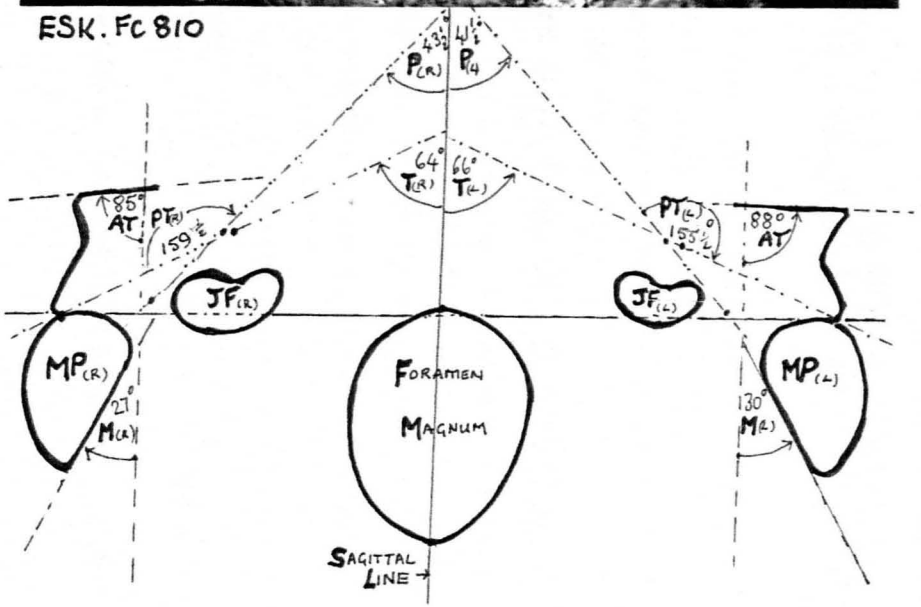
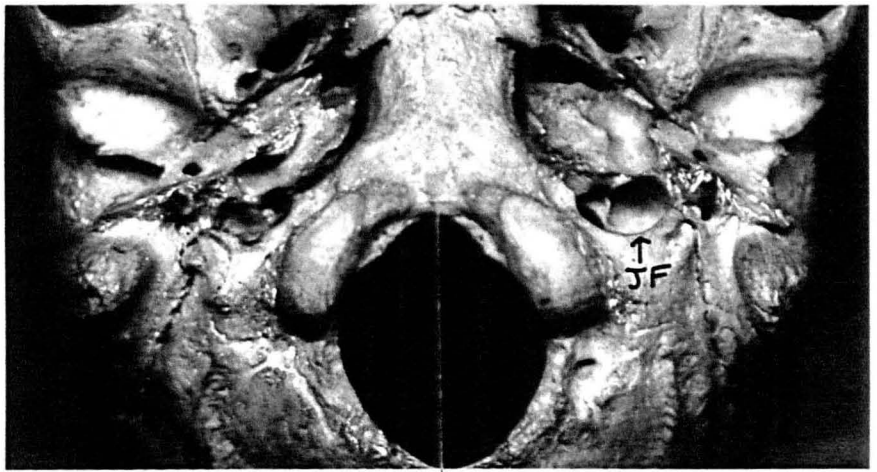


b) In the rarer case, when the left jugular fossa is the larger, the tympanic axis, the anterior side of the tympanic plate and the mastoid axis are more sagitally inclined on the left, the left petrous axis is more coronally oriented than the right and the left petrous-tympanic angle is larger than the right.



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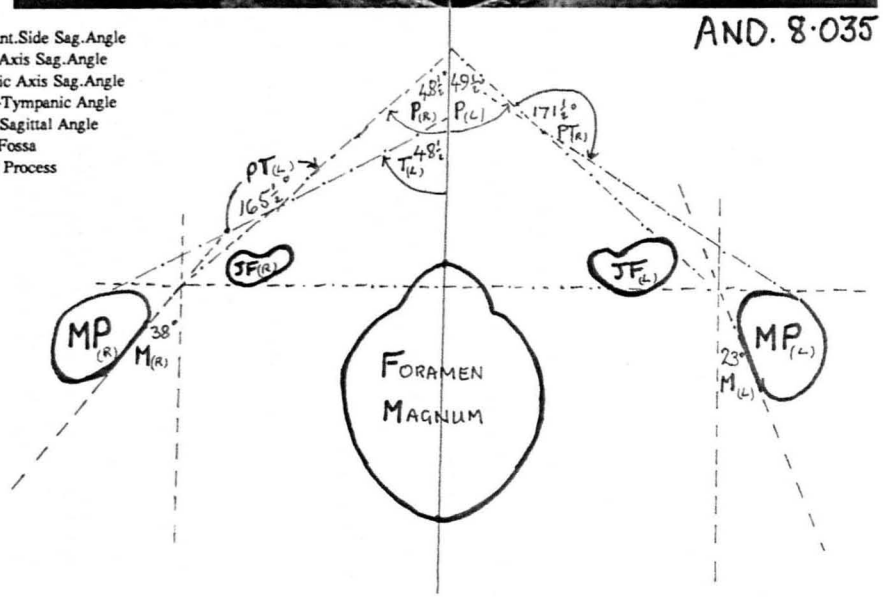

AT = Tymp.Ant.Side Sag.Angle
P = Petrous Axis Sag.Angle
T = Tympanic Axis Sag.Angle
PT = Petrous-Tympanic Angle
M = Mastoid Sagittal Angle
JF = Jugular Fossa
MP = Mastoid Process

4.4.2.4 DISCUSSION AND SUMMARY

Pursuit in the literature of the reason for the asymmetry in jugular fossa size and in sigmoid sulcus size shows that they are closely connected and together may account for most temporal asymmetry.

The right transverse (lateral) sinus is usually considerably larger than the left since it receives blood from the large superior sagittal sinus, whereas the left transverse sinus is continuous with the smaller straight sinus. The right sigmoid sinus, formed from the combined transverse and superior petrous sinuses, is thus larger than the left (Fig.4.4.5). The right sigmoid sulcus shows the same asymmetry (though the size of an endocranial sulcus is said to not necessarily correspond to the capacity of its associated sinus (Aiello & Dean 1990:172)). The sigmoid sinus joins the inferior petrous sinus to leave the cranial cavity via the jugular foramen as the internal jugular vein. The right internal jugular vein is usually larger than the left. The superior part of the internal jugular vein, the jugular bulb, is lodged in the jugular fossa, which also is usually larger on the right side than the left (Aiello & Dean 1990:169,170-172; Frazer 1920:196; Gray 1993:421,425,426).

It is proposed that these aspects of asymmetry in the intracranial blood flow in modern humans make an important contribution to the asymmetry observed in the temporal bone. The close association between the asymmetry of the sigmoid sulcus size and jugular fossa size also implies a link between most temporal variable asymmetries, since it has been shown already that jugular fossa size affects petrous and tympanic angles, and sigmoid sulcus and mastoid size relates to glenoid fossa size and external auditory meatus angle (Figs.4.4.3,4).

Cerebellar fossae asymmetry may also partly contribute to temporal asymmetry since it is reported that usually the right sigmoid sinus is positioned more anteriorly than the left (Frazer 1920:196). However, further investigation of such possible relationships is beyond the scope of this study.

Chapter 5 VARIATION IN THE MODERN HUMAN TEMPORAL BONE

5.1 PURPOSE AND PROCEDURE

Do the Australians differ noticeably from other modern populations in temporal features, and if so do they differ more in temporal features than they do in non-temporal features? To answer these questions, variation between 11 modern population groups was examined for 55 variables which included 26 temporal and 29 non-temporal variables[1]. In this introductory investigation, three aspects were considered:

group distribution of values,
differences in group means and
variation of group means with cranial size.

a) DISTRIBUTION OF VALUES.

In the comparison of the distribution of absolute values for the 55 variables in 11 population groups, summary statistics are displayed in box plots. Group distributions are arranged in order of increasing cranial size as defined below.

In each box plot, the 25th. and 75th. percentiles are plotted so that 50% of cases have values within the box. Values between 1.5 and 3 box lengths from upper or lower edge of the box are "outliers", identified with a circle. Vertical lines are drawn from the ends of the box to the largest and smallest absolute values which are <u>not</u> outliers. The box plots display the median, but statistics undertaken here involve the group mean. The box plots are the first in the paired plots of Figs.5.3.3.1-26 (Temporal) & 5.4.3.1-29 (Non-temporal).

Group means and standard deviation for the 55 variables are recorded in Appendix Table A.5.1, and their correlation coefficients in Appendix Table A.5.2.

b) SIGNIFICANT DIFFERENCES BETWEEN GROUP MEANS.

Pairwise comparison of group means for each of the 55 variables was made using Scheffe's test, the most stringent of

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[1] Insufficient sample numbers exclude internal petrous transverse angle from the between-groups variation analysis.

the tests available in SPSS for comparison between groups; it requires larger differences between means for significance than do the other tests. All variable data was tested for normality, this being an assumption for analysis of variance procedures. Consequently, 10 temporal and 5 non-temporal variables (identified in Appendix Table A.5.5) were transformed by taking the square root or $\log_{10}$ to minimise skewness and kurtosis.

In the same table are recorded the F values and corresponding significance levels found in Oneway Analysis of Variance for each variable. The Scheffe's test findings are summarised to show the number of variables in which each group differs significantly from other groups in Appendix Tables A.5.6.1-4 (Temporal) and A.5.8.1-3 (Non-temporal).

c) VARIATION OF GROUP MEANS WITH CRANIAL SIZE.

Estimation of overall cranial size was made on the dimensions of overall cranial length, breadth and height. Further references to "cranial size" in this chapter are to be understood in terms of the following definition:

CRANIAL SIZE = [Cub.rt.(GOL x AUB x BBH)]/100
= [Antilog 1/3(log GOL + log AUB + log BBH)]/100
GOL = Glabella-Opisthocranion Length
AUB = Biauricular Breadth
BBH = Bregma Basion Height

Group means and standard deviation for cranial size as defined above are recorded in Appendix Table A.5.3. Correlation coefficients of variables with cranial size are recorded in Appendix Tables A.5.4 (Temporal) and A.5.7 (Non-temporal). Variables are listed in order of decreasing Pearson correlation coefficient (r) values, and grouped in three categories, positively correlated, negatively correlated and uncorrelated at $p<.001$. Also recorded in Appendix Tables A.5.4 and A.5.7 are the correlation coefficients (R) of variable group means with cranial size group means. (It is the square of the correlation coefficient which indicates the strength of the association between a pair of variables, and 100 x r^2 is the percentage of explained variance. However, the unsquared coefficient is quoted in preference because it also indicates

whether the association is positive or negative.)

For each of the 55 variables, group means are plotted against cranial size group means. These bivariate plots are the second in the paired plots recorded in Figs.5.3.1-26 (Temporal) and Figs.5.4.1-29 (Non-temporal). In the footnote accompanying each plot is recorded in brackets the correlation coefficient (r) of the variable with cranial size for the combined 11 groups. If the correlation is significant at $p<.001$, the linear regression equation and correlation coefficient of variable group means with cranial group means (R) are also quoted in the footnote.

Because of missing values, cranial size could not be estimated for 3 of the 447 crania. Also, a small number of cases had one or more variable values missing. Consequently, the number of cases included in a particular bivariate plot may not correspond exactly to the number of cases represented in the corresponding box plot.

Temporal variables and non-temporal variables are considered separately in Sections 5.3 and 5.4 respectively.

5.2 CRANIAL SIZE VARIATION BETWEEN GROUPS

The cranial size distribution is depicted in Fig.5.2.1 for 11 population groups and in Fig.5.2.2 for 6 groups. The absolute mean values indicate that Andamanese and Bushman crania are particularly small, Fuegian and Eskimo particularly large, and Australian intermediate (Appendix Table A.5.1).

Scheffe's test shows that Andamanese mean cranial size is significantly smaller than that of all groups except Bushman and Veddah; Fuegian and Eskimo are significantly larger than all except Poundbury and Chinese; Australian cranial mean size is significantly smaller than Fuegian and Eskimo; and significantly larger than Andamanese or Bushman ($F=34.8$, $p=.000$, Appendix Table A.5.5).

The relationship of the variables to the size of the cranium is examined in greater detail in the next chapter when the results of factor analysis are considered.

5.3 TEMPORAL VARIABLES

5.3.1 CORRELATION WITH CRANIAL SIZE

All linear temporal variables except anteriority of basion and tympanic rim indent show significant positive correlation with cranial size at $p<.001$ (Appendix Table A.5.4). The strength of the associations varied from moderate to very weak. The highest correlation is for glenoid fossa ant./post.length ($r=.650$, $p=.000$) and accounts for 42.5% of the variation; the lowest significant correlation is for foramen magnum centre position ($r=.235$, $p=.000$) and accounts for merely 5.5% of the variation.

Two variables, mastoid axis angle and mastoid-suprameatal angle, show negative though very weak correlation with cranial size. The other 6 angular measurements and glenoid fossa ratio show no correlation with cranial size at $p<.001$; angles of petrous, tympanic axis and tympanic anterior side have very weak but significant correlation with cranial size at $p<.05$.

5.3.2 SIGNIFICANT DIFFERENCES BETWEEN GROUPS IN ABSOLUTE MEANS

One-way Analysis of Variance found that there is significant difference between group absolute means for 24 of the 26 temporal variables ($p=.0000$; Appendix Table A.5.5). For the 2 exceptions, anteriority of basion and external auditory meatus angle, a difference in group means exists at significance $p=.004$ and $p=.01$ respectively.

Scheffe's test identified the groups between which significant differences in means occurs for a particular variable. Appx.Tables A.5.6.1-3 record the number of times each group differs significantly in absolute means from another group. In Appendix Table A.5.6.1, each number corresponds to the number of linear temporal variables which are significantly greater for the vertically listed group than for the corresponding horizontally named group. e.g. Australians have significantly greater mean values than do Gabon for 6 temporal linear variables. Each number also corresponds to the number of linear temporal variables which are significantly smaller for the horizontally named group than for the vertically listed group. e.g. Australians have significantly smaller mean values than do Chinese in 4 temporal linear variables. In the same way, Appendix Table

A.5.6.2 records the number of significant differences in group means of 9 non-linear temporal variables.

In both tables, the groups are ordered according to increasing cranial size from left to right and from top to bottom. Thus it can be seen from Appendix Table A.5.6.1 that there is some tendency for groups associated with larger crania to have a greater number of temporal linear variables with significantly higher group mean values than those of other groups. No such tendency is evident in the results in Appendix Table A.5.6.2 for non-linear temporal variables. Rather, significant differences in non-linear means occur considerably more often for Australians and Eskimos than for other groups, Australians tending to have significantly smaller angles and Eskimos significantly larger angles than other groups.

A quantitative estimate of which groups differ most can be gained from Appendix Table A.5.6.3 in which is recorded the total number of significant differences in means for each group. The summary in Appendix Table A.5.6.4 shows the tendency of a particular group to have a significantly greater or less absolute mean than other groups for a particular variable.

SUMMARY: There is a tendency for groups with larger crania to have significantly larger mean values for linear temporal variables than those of other groups. This tendency is not true for non-linear (angular) temporal measurements, in which Australians and Eskimos have the greatest number of significant differences. Andamanese differ significantly in temporal variable means the greatest number of times (89), then Eskimo and Chinese (73). Veddah differ significantly least often of all groups (29), and Gabon differ least often of the 6 large sample, regionally distinct groups.

Scheffé's test identified which groups the significant differences in group means referred to; this aspect of the results has been incorporated in the following discussion of group variance for each variable. Appendix Table A.5.6.4 records the tendency of each group to have significantly greater or less absolute means than other groups for a particular variable.

Fig.5.2.1.Cranial Size based on Length, Breadth & Height, 11 groups.

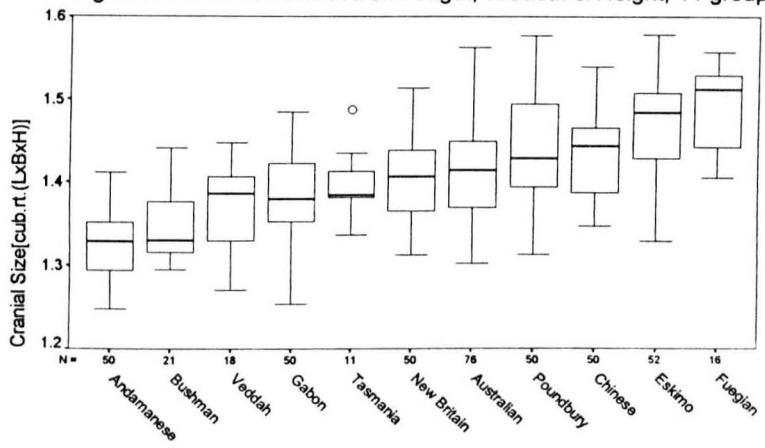


Fig.5.2.2.Cranial Size based on Length, Breadth & Height, 6 Groups.

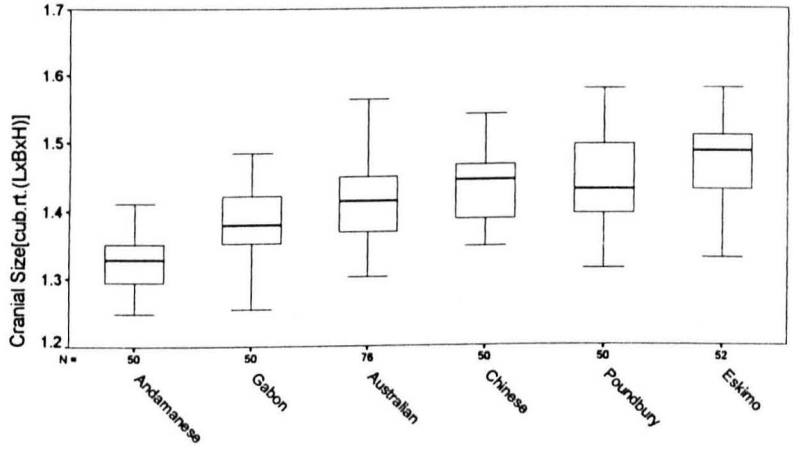


Fig.5.3.1a Glenoid Fossa ant/post.Length

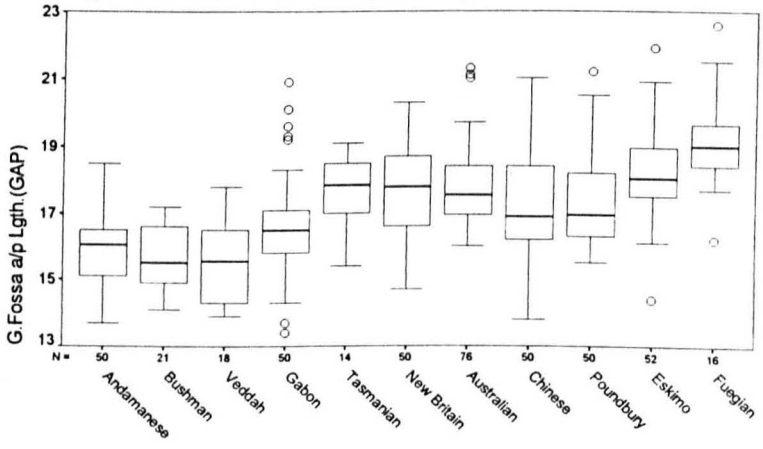
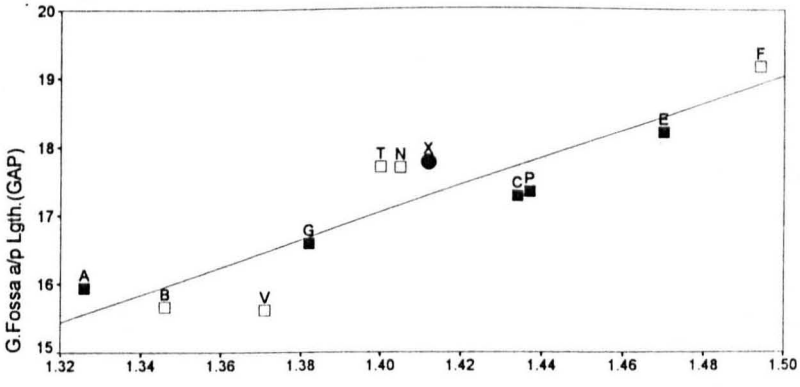


Fig.5.3.1b Glenoid Fossa ant./post.Length vs. Cranial Size



GAP = 19.9 LBH - 10.8; R =.897, p=.000, n=11. (r=.650, p=.000, n=444)

Fig.5.3.2a Glenoid Fossa med/lat. Width

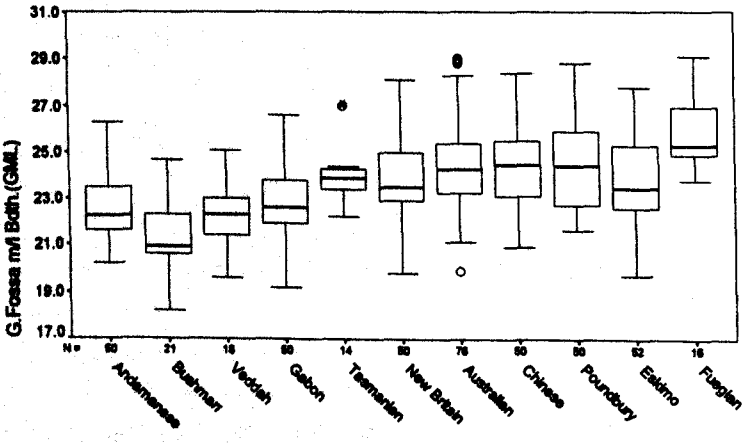
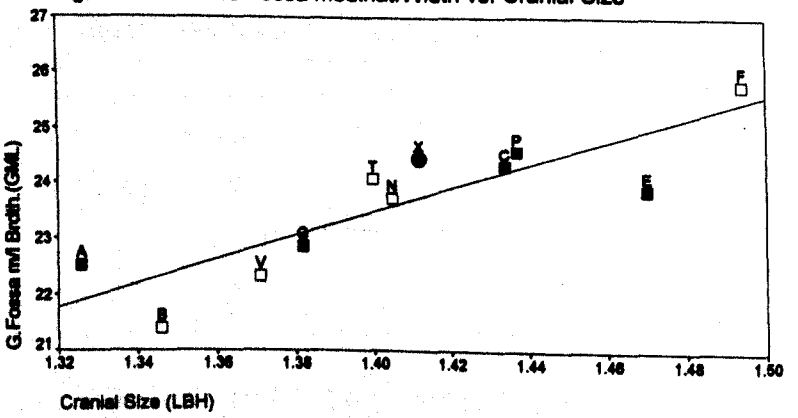


Fig.5.3.2b Glenoid Fossa med./lat.Width vs. Cranial Size



GML = 21.4 LBH - 6.43; R =.865, p=.001, n=11. (r =.564, p =.000, n=444)

Fig.5.3.3a Glenoid Fossa Depth

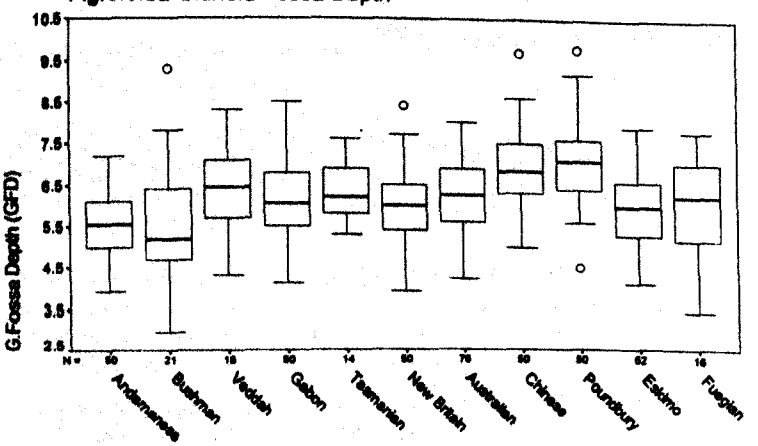
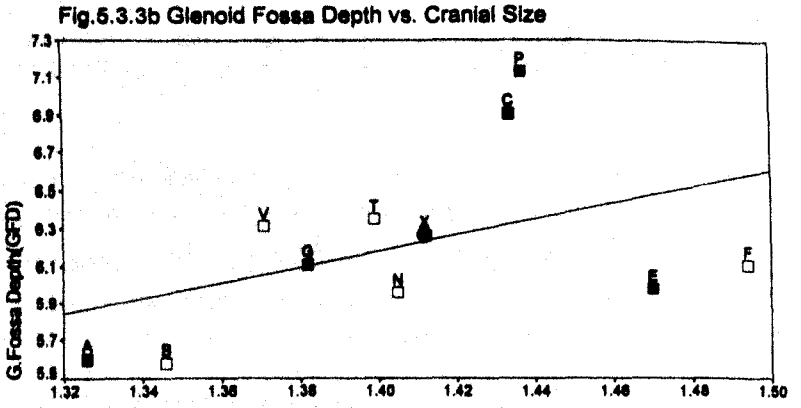


Fig.5.3.3b Glenoid Fossa Depth vs. Cranial Size



GFD = 4.27 LBH + .197; R =.453,p=.162,n=11; (r =.362, p =.000, n=444)

5.3.3 BETWEEN-GROUPS VARIATION FOR EACH TEMPORAL VARIABLE

For each temporal variable in turn, 4 aspects of variation are considered

(i) between groups variation of absolute values;
(ii) existence of significant difference in group means;
(iii) correlation with cranial size for the combined total sample;
(iv) association of group means with cranial size group means.

NOTE: When the word "relative" is used it is to be understood to mean "relative to cranial size".

5.3.3.1-6 GLENOID FOSSA. 6 glenoid fossa variables are considered; the first 3 are direct measurements, the others are derived.

5.3.3.1 GLENOID FOSSA Ant./Post. LENGTH (GAP). According to the absolute value distributions and absolute means (Fig.5.3.1a and Appendix Table A.5.1), Fuegian and Eskimo groups have the longest glenoid fossa, Veddah and Bushman the smallest. The absolute mean of Fuegians, is significantly greater than that of all groups except Eskimos; the Australian mean is significantly smaller than that those 2 groups, but larger than that of Andamanese, Bushman, Veddah and Gabon (p=.0000).

Of the 26 temporal variables, glenoid fossa length has the strongest (positive) correlation with cranial size (r=.651, p=.000, Appendix Table A.5.4). The group means are also strongly correlated with cranial size group means (R=.897, p=.000). Compared to other groups and relative to cranial size, Australian, New Britain and Tasmanian means are large, Veddah mean is small (Fig.5.3.1b).

5.3.3.2 GLENOID FOSSA Med./Lat. WIDTH (GML). According to the absolute value distributions and absolute means (Fig.5.3.2a and Appendix Table A.5.1), the glenoid fossa is particularly wide for Fuegians and particularly narrow for Bushman. The absolute means of Fuegians, Australians and Poundbury are significantly larger than those of Gabon, Andamanese, Veddah and Bushman (p=.0000).

There is moderate positive correlation of glenoid fossa breadth with cranial size (r=.594, p=.000) and quite a strong

correlation of group means with cranial size group means (R=.865, p=.001; Appendix Table A.5.4). Compared to other groups and relative to cranial size, Australian, Tasmanian and Andamanese means are large, Bushman and Eskimo means are small (Fig.5.3.2b).

5.3.3.3 GLENOID FOSSA DEPTH (GFD). According to the absolute value distributions and absolute means (Fig.5.3.3a and Appendix Table A.5.1), the glenoid fossa of Chinese and Poundbury is particularly deep, that of Bushman is shallow. The absolute means of Chinese and Poundbury are significantly larger than all groups except Fuegian and Tasmanian at p=.0000.

There is positive but weak correlation of glenoid fossa depth with cranial size, accounting for only 12.4% of variation (r=.352, p=.000). The correlation of glenoid fossa depth group means with cranial size group means is also weak and positive (R=.453, p=.162; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the glenoid fossa of Chinese and Poundbury is deep, that of Eskimo and Fuegian groups is shallow (Fig.5.3.3b).

5.3.3.4 GLENOID FOSSA AREA (GFA). According to the absolute value distributions and absolute means (Fig.5.3.4a and Appendix Table A.5.1), Fuegian and Eskimo glenoid fossa area is large, that of Bushman is small. The absolute means of Fuegian, Eskimo, New Britain and Australian groups are significantly larger than those of Bushman, Veddah and Andamanese; Fuegian mean is also significantly greater than that of Poundbury (p=.0000).

There is moderate, positive correlation of glenoid fossa area with cranial size (r=.618, p=.000) and strong correlation of group means with cranial size group means (R=.940, p=.000; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the glenoid fossa area of Australian and New Britain groups is large (Fig.5.3.4b).

In a study based on a time-successive series of genetically homogeneous populations spanning 10,00 years and representing a transition from hunting and gathering economy to an agricultural one, Hinton and Carlson found an appreciable reduction in glenoid fossa size and corresponding

reduction in temporomandibular joint dimensions from hunter/gatherers to those dependent on agricultural subsistence (Hinton & Carlson 1979:331,332). The comparatively large glenoid fossa area of Australian and New Britain crania absolutely and relative to cranial size is consistent with the expectation of large fossa size for hunter-gatherers, though the relatively small glenoid fossa area of Bushman and Eskimo crania indicates other factors are involved.

5.3.3.5 GLENOID FOSSA VOLUME (GFV). According to the absolute value distributions and absolute means (Fig.5.3.5a and Appendix Table A.5.1), Bushman and Andamanese have the smallest glenoid fossa volume, Fuegian, Poundbury and Chinese the largest. The absolute means of Bushman and Andamanese are significantly smaller than those of all groups except Veddah and Gabon at p=.0000.

There is moderate, positive correlation of glenoid fossa volume with cranial size (r=.609, p=.000) and quite strong correlation of group means with cranial size group means (R=.849, p=.001; Appendix Table A.5.4). Eskimo and Fuegian groups have a small glenoid fossa volume relative to cranial size, but otherwise a strong linear relationship is evident (Fig.5.3.5b). If Eskimos and Fuegians are omitted in the plot, this trend is even clearer and the correlation increases to r=.950, p=.000).

5.3.3.6 GLENOID FOSSA LENGTH/WIDTH RATIO (GFIDX). According to the absolute value distributions and absolute means (Fig.5.3.6a and Appendix Table A.5.1), Andamanese, Veddah, Poundbury and Chinese have the smallest glenoid fossa ratios (i.e. are wide compared to ant./post. length). The absolute mean of Eskimos is significantly greater than that of Andamanese, Poundbury and Veddah at p=.0000.

There is no significant correlation of glenoid fossa ratio with cranial size (r=.123, p<.010), nor of glenoid fossa ratio group means with cranial size group means (R=.467, p=.147; Appendix Table A.5.4 and Fig.5.3.6b).

SUMMARY: Correlation of glenoid fossa dimensions with cranial size is positive and moderately strong for volume, ant./post. length and med./lat. breadth, weakly positive for

Fig.5.3.4a Glenoid Fossa Area

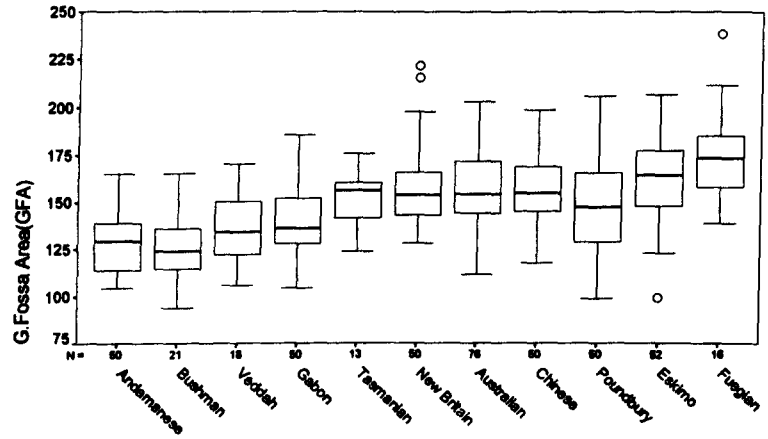
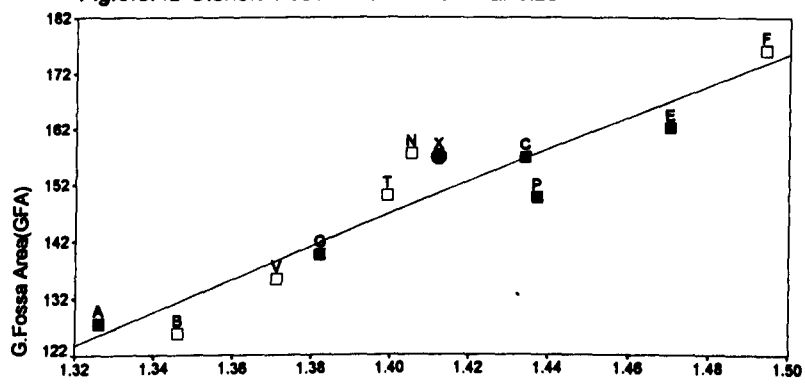


Fig.5.3.4b Glenoid Fossa Area vs. Cranial Size



GFA = 287.6 LBH -256.7; R =.940, p=.000,n=11; (r =.618, p =.000, n=444)

Fig.5.3.5a Glenoid Fossa Volume

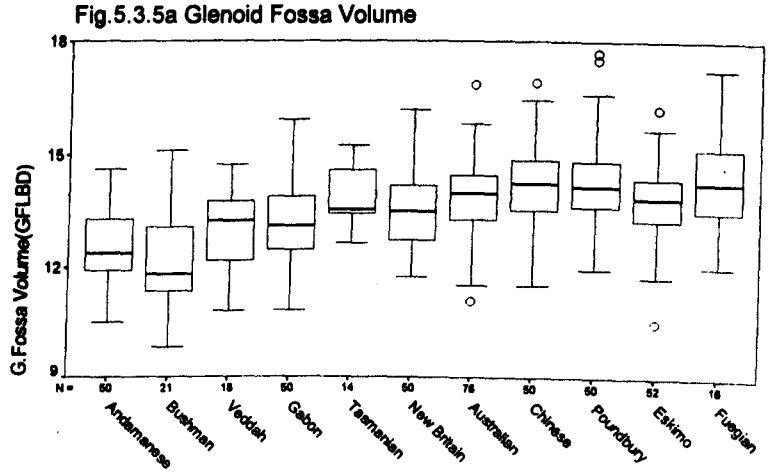
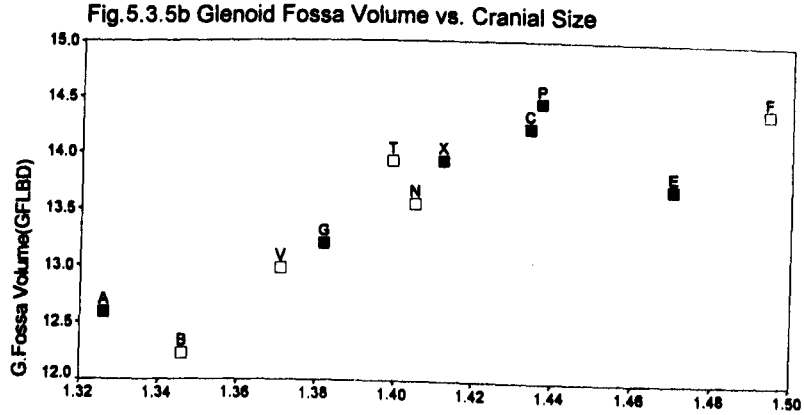


Fig.5.3.5b Glenoid Fossa Volume vs. Cranial Size



GFLBD = 12.4 LBH - 3.87; R= .849, p=.001, n=11. (r =.609, p=.000,n=444)

Fig.5.3.6a Glenoid Fossa ant.-post./med.-lat. Ratio

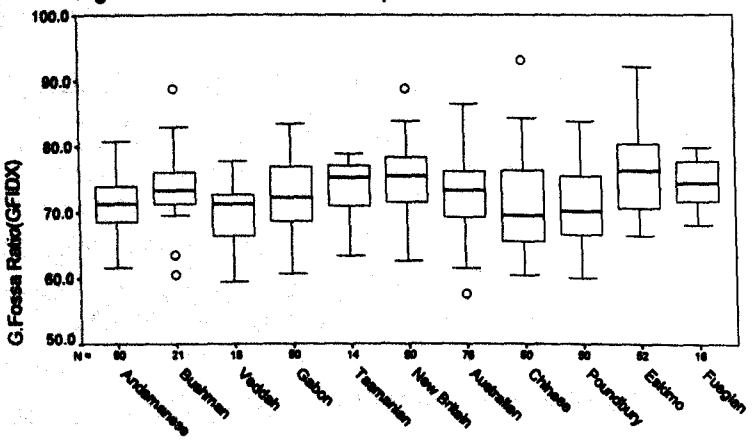
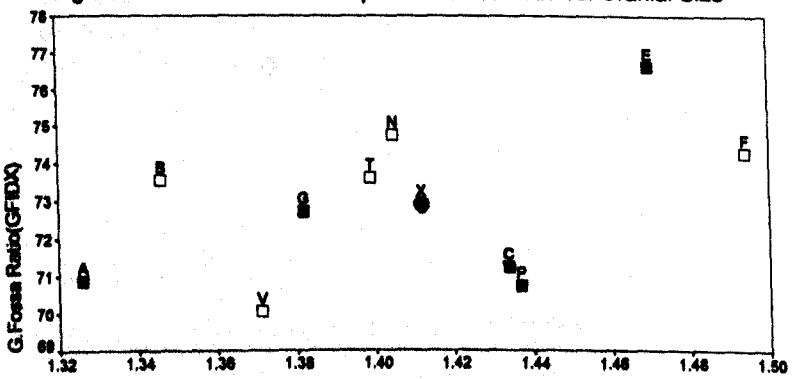


Fig.5.3.6b Glenoid Fossa ant.-post./med.-lat.Ratio vs. Cranial Size



(r =.123, p =.010, n=444)

Fig.5.3.7a Temporal Squamous Height

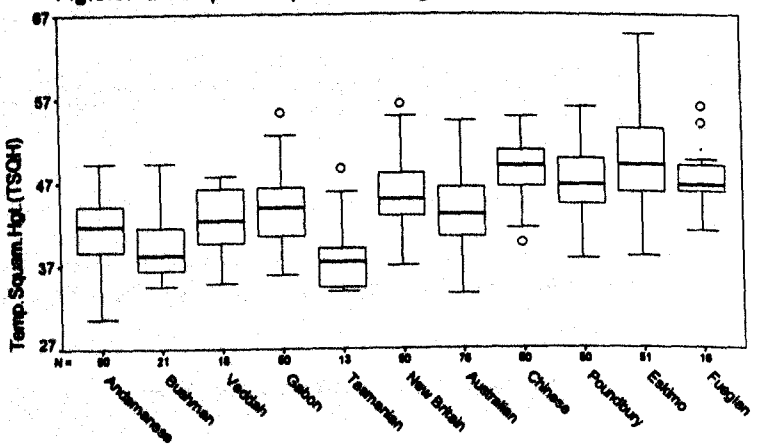
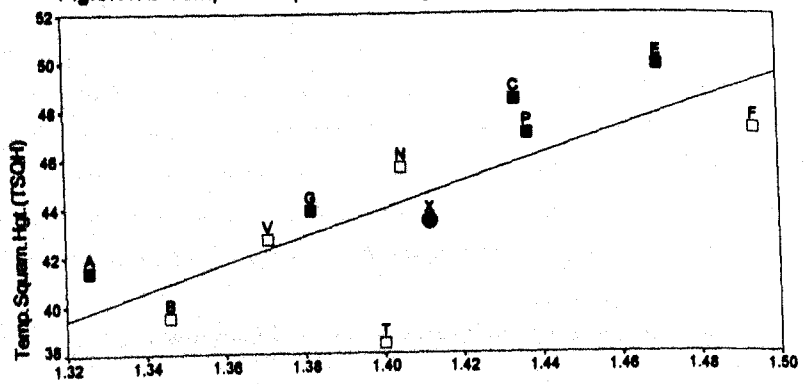


Fig.5.3.7b Temporal Squamous Height vs. Cranial Size



TSQH = 56.3 LBH - 34.9; R =.773,p =.005,n=11. (r =.619, p =.000,n =443)

depth, and negligible for length/width ratio.

Glenoid fossa dimensions for Australians compared to other groups are relatively and absolutely large for length, and breadth, relatively large for area, and intermediate in depth, volume and length/width ratio.

The Bushman glenoid fossa is notably small in all dimensions; that of Eskimos and Fuegians is shallow and small in volume relative to cranial size, though Fuegians have the largest absolute means for breadth, length, area and volume.

5.3.3.7 TEMPORAL SQUAMOUS HEIGHT (TSQH). According to the absolute value distributions and absolute means (Fig.5.3.7a and Appendix Table A.5.1), Bushman and Tasmanian groups have the lowest Temporal squamous, Eskimo and Chinese the highest. The absolute means of Chinese and Eskimo are significantly greater than all groups except Poundbury, New Britain and Fuegian. Andamanese, Bushman and Tasmanian means are significantly lower than all except Australian, Gabon and Veddah; and the Australian means is significantly lower than those of Eskimo, Chinese and Poundbury groups (p=.0000).

Correlation is positive and moderate for temporal squamous height with cranial size (r=.619, p=.000), and for temporal squamous height group means with cranial size group means (r=.773, p=.005; Appendix Table A.5.4). Compared to other groups and relative to cranial size, Australian, Bushman, Fuegian and especially Tasmanians have small temporal squamous height; Eskimo and Chinese groups have a relatively high temporal squamous (Fig.5.3.7b).

5.3.3.8-11 MASTOID PROCESS DIMENSIONS 4 mastoid process linear variables are considered; the first 3 are direct measurements.

5.3.3.8 MASTOID PROCESS LENGTH (MPL) According to the absolute value distributions and means (Fig.5.3.8a and Appendix Table A.5.1), Fuegian, Poundbury, Australian, and Chinese have the longest mastoid process, and the Tasmanian mastoid is particularly short. Of the absolute group means, Chinese, Fuegian and Australian are significantly greater than Tasmanian, Bushman and Andamanese; Poundbury is also significantly greater than Gabon and Eskimos; and Tasmanian is significantly less than Fuegian, Poundbury, Australian,

Chinese and New Britain (p=.0000).

Correlation is positive and moderate for mastoid length with cranial size (r=.554, p=.000), and for mastoid length means with cranial size means (r=.660, p=.027; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the mastoid process of Australian and Poundbury crania is long, that of Tasmanians and Eskimos is short (Fig.5.3.8b).

5.3.3.9 MASTOID PROCESS WIDTH (MPW). According to the absolute value distributions and means (Fig.5.3.9a and Appendix Table A.5.1), the mastoid process is widest for Fuegian, Poundbury, and Chinese and narrowest for Tasmanian and Andamanese. Of the absolute group means, Fuegian, Poundbury and Chinese are significantly greater than Australians and all other groups except Veddah and New Britain; Poundbury and Fuegian are also significantly greater than Veddah; Fuegian is also significantly greater than New Britain (p=.0000).

Correlation is positive and moderate for mastoid width with cranial size (r=.540, p=.000), and for mastoid width group means with cranial size group means (r=.703, p=.016; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the mastoid process is wide for Fuegian, Poundbury and Chinese crania and particularly narrow for Tasmanians and Eskimos (Fig.5.3.9b).

5.3.3.10 MASTOID PROCESS DEPTH average (MPD). According to the absolute value distributions and means (Fig.5.3.10a and Appendix Table A.5.1), mastoid process depth (a transverse axis dimension) is greatest for Fuegian, New Britain and Australian groups and least for Gabon. The absolute mean of Gabon is significantly smaller than Chinese, Poundbury and Fuegian means. The absolute means of Australian and New Britain are significantly larger than those of Gabon and Andamanese at p=.0000.

Correlation is positive and moderate for mastoid depth with cranial size (r=.494, p=.000), and for mastoid depth group means with cranial size means (r=.752, p=.008; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the Australian and New Britain mastoid process is deep; the Gabon and Eskimo relative transverse dimension is

Fig.5.3.8a Mastoid Process Length

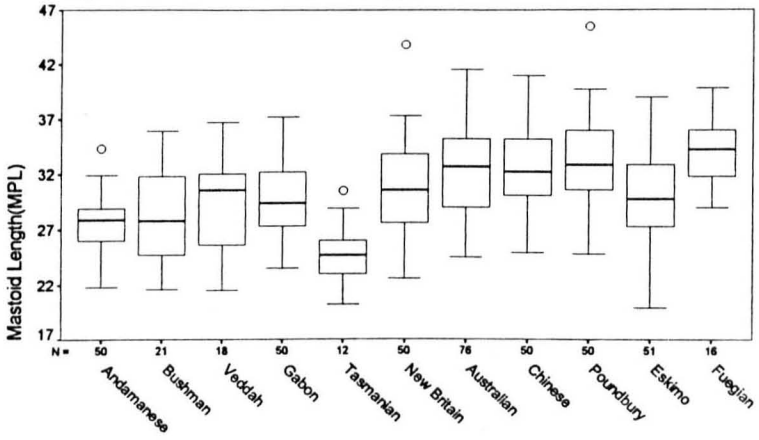
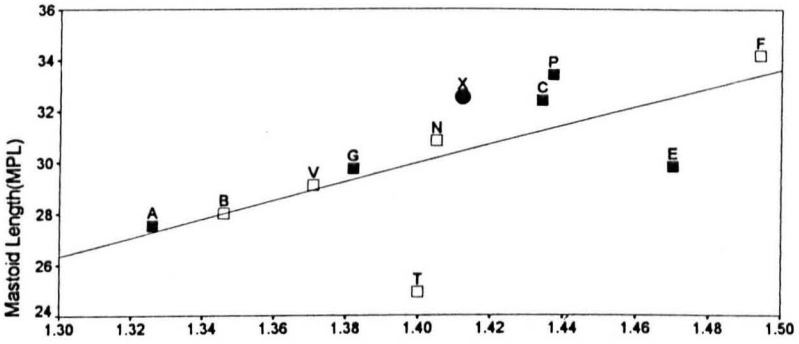


Fig.5.3.8b Mastoid Process Length vs. Cranial Size



MPL = 36.5 LBH - 21.2; R=.660, p=.027, n=11. (r =.554, p =.000, n=442)

Tasmanian & Eskimo mastoids are short relative to cranial size.

Fig.5.3.9a Mastoid Process Width

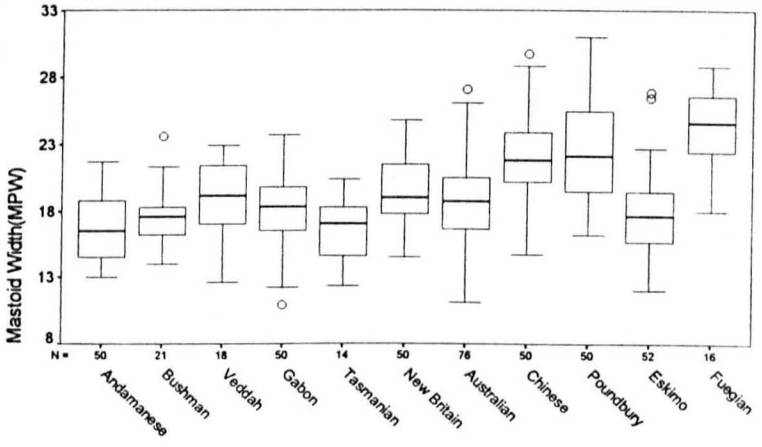
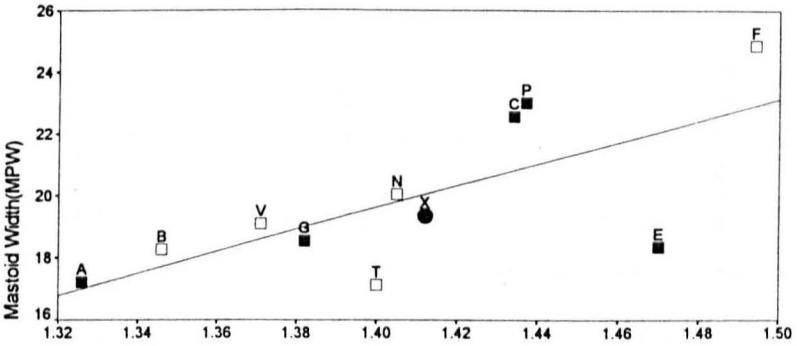


Fig.5.3.9b Mastoid Process Width vs. Cranial Size



MPW = 35.5 LBH - 30.6; R =.703, p=.016,n =11. (r =.540, p =.000, n =444)

Eskimo & Tasmanian mastoids are narrow relative to cranial size.

Fig.5.3.10a. Mastoid Process Transverse Depth

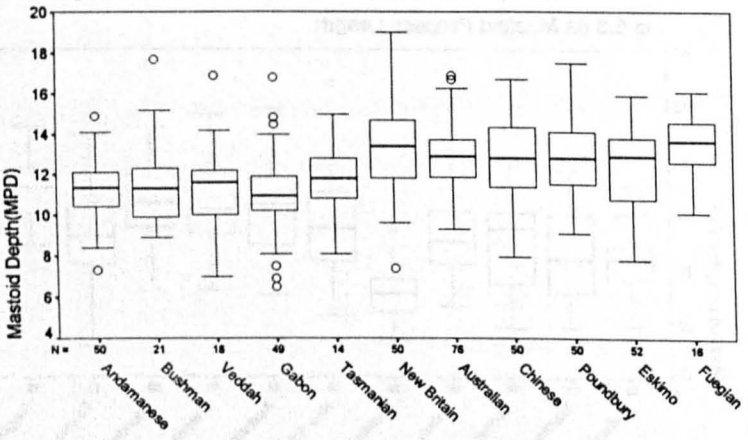
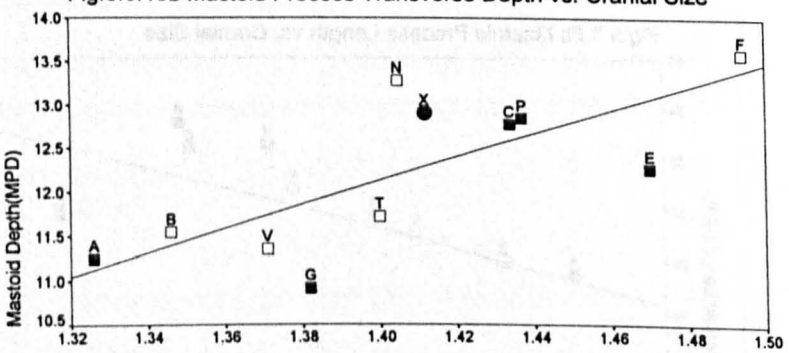


Fig.5.3.10b Mastoid Process Transverse Depth vs. Cranial Size



MPD = 13.6 LBH - 6.90; R=.752, p=.008, n=11. (r =.494, p =.000, n=443)

Relative mastoid depth is large in Aust.& New B., small in Esk.& Gab.

Fig.5.3.11a Mastoid Process Volume

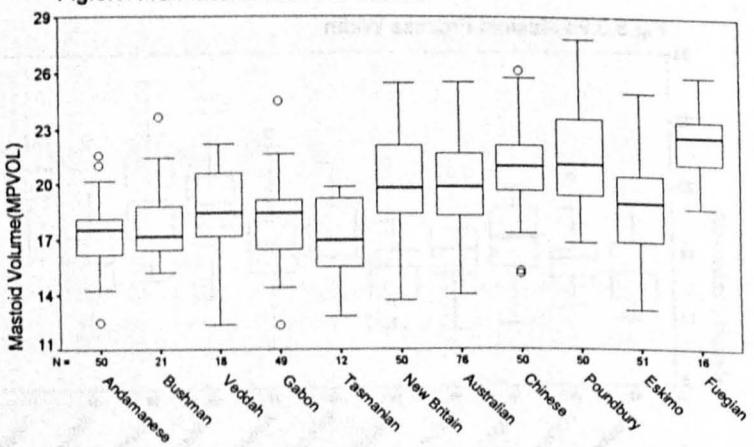
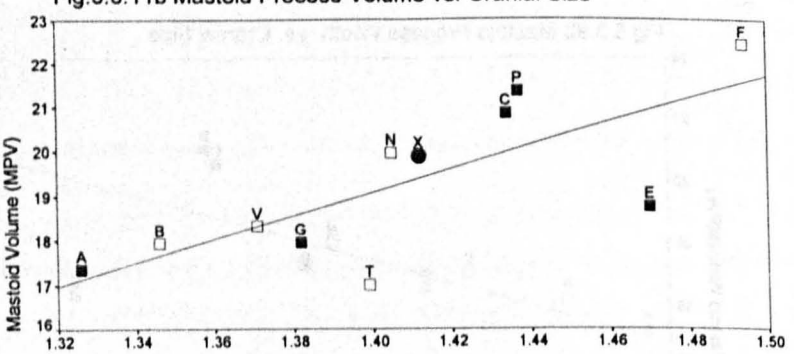


Fig.5.3.11b Mastoid Process Volume vs. Cranial Size



MPVOL= 26.5 LBH - 17.7; R=.754, p=.007, n=11. (r =.615, p =.000. n=441)

Mastoid volume in Tasmanian & Eskimo crania is relatively small.

particularly small (Fig.5.3.10b).

5.3.3.11 MASTOID PROCESS VOLUME (MPV). The absolute value distributions and means (Fig.5.3.11a & Appendix Table A.5.1) indicate the mastoid process volume of Fuegians is particularly large and that of Tasmanians particularly small. Of the absolute group means, Fuegian, Poundbury and Chinese are significantly greater than Tasmanian, Andamanese, Gabon, Bushman and Eskimo; Poundbury and Fuegian are also significantly greater than Veddah; and Australian is significantly greater than Andamanese and Gabon (p=.0000).

Correlation is positive and moderate for mastoid volume with cranial size (r=.615, p=.000), and for mastoid volume group means with cranial size group means (r=.754, p=.007; Appendix Table A.5.4). Compared to other groups and relative to cranial size, Tasmanians and Eskimos have a small mastoid process volume (Fig.5.3.11b). Duckworth and Pain (1900:135) identified the comparatively small size of the Eskimo mastoid process as an hereditary character since it is evident in Eskimo juveniles. In the present investigation also Eskimo juveniles were observed to have a small mastoid relative to cranial size as noted in Ch.3 Section 3.2.1 and Fig.3.2.3b.

SUMMARY: Correlation of mastoid process dimensions with cranial size is positive and moderate in strength. In terms of absolute values, the mastoid process of Fuegians is the longest, widest, deepest and of greatest volume, that of Tasmanians is the shortest, narrowest and of least volume, that of Gabon is smallest in depth. The Australian mastoid is long and very deep but somewhat narrow and of merely intermediate volume.

Relative to cranial size, the mastoid of Australian and New Britain is deep, Australian and Poundbury mastoid is long, Chinese and Poundbury mastoid is wide, Eskimo and Tasmanian mastoid is small in volume, width and length, and Eskimo and Gabon mastoid is small in depth.

5.3.3.12–15 <u>TYMPANIC PLATE DIMENSIONS</u> 4 are considered.

5.3.3.12 TYMPANIC PLATE LENGTH (TPL). According to absolute value distributions and means (Fig.5.3.12a and Appendix Table A.5.1), Fuegian, and Eskimos and Australians have the longest tympanic plate, and Bushman, Veddah and Andamanese the

shortest. The absolute group mean of Fuegians is significantly greater than that of all other groups; the absolute means of Australians and Eskimos are significantly greater than those of Andamanese and Bushman (p=.0000).

Correlation is positive and moderate for tympanic plate length with cranial size (r=.553, p=.000), and positive and strong for tympanic plate length group means with cranial size group means (r=.884, p=.000; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the tympanic plate of Fuegian and Gabon is long (Fig.5.3.12b).

5.3.3.13 TYMPANIC PLATE HEIGHT (TPH). According to absolute value distributions and means (Fig.5.3.13a and Appendix Table A.5.1), Chinese have the highest tympanic plate, Tasmanian and Andamanese the lowest. The Chinese absolute group mean is significantly greater than that of all other groups except Fuegian and Poundbury; Andamanese and Tasmanian means are significantly less than those of Eskimo, Gabon, Fuegian, Poundbury and Chinese; the Australian mean is significantly less than Poundbury and Chinese means (p=.0000).

Correlation is positive and quite weak for tympanic plate height with cranial size (only 16.7% of variation is accounted for, r=.409, p=.000). There is also weak, positive correlation of tympanic plate height group means with cranial size group means (r=.575, p=.064; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the tympanic plate is particularly high for Chinese and low for Tasmanians (Fig.5.3.13b).

5.3.3.14 TYMPANIC PLATE LATERAL RIM THICKNESS (TTHK). According to absolute value distributions and means (Fig.5.3.14a and Appendix Table A.5.1), Eskimos have a very thick tympanic plate lateral rim, Andamanese have a very thin one. Of the absolute group means, that of Eskimos is significantly greater than that of all other groups, that of Australians is significantly greater than those of Andamanese, Bushman, Chinese, New Britain, and Gabon, and that of Andamanese is significantly less than all groups except Bushman at p=.0000.

Correlation is positive and weak for tympanic plate rim thickness with cranial size (20.4% of variance accounted for,

Fig.5.3.12a Tympanic Plate Length

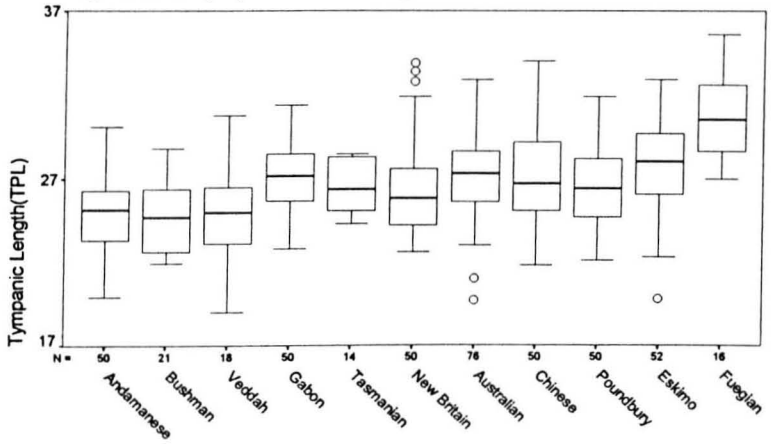
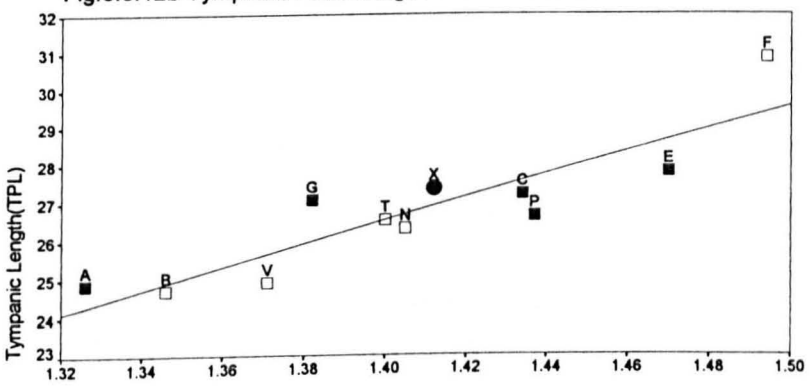


Fig.5.3.12b Tympanic Plate Length vs. Cranial Size



Cranial Size (LBH)

TPL = 30.3 LBH - 16.0; R=.884, p=.000, n=11. (r =.553, p =.000, n=444)

Fig.5.3.13a Tympanic Plate Height

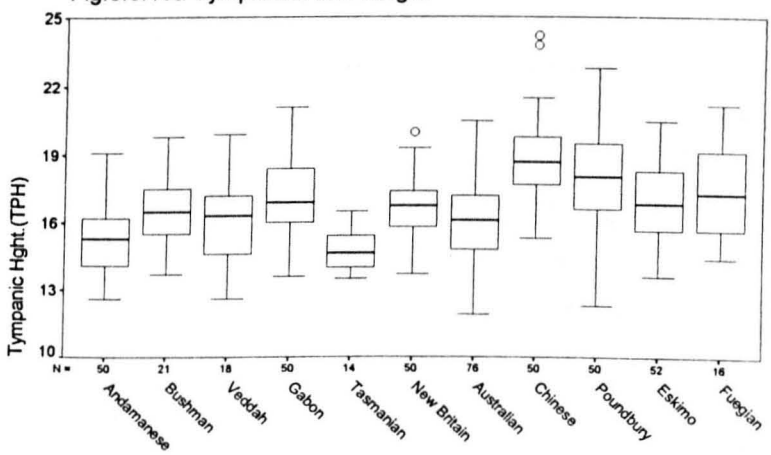
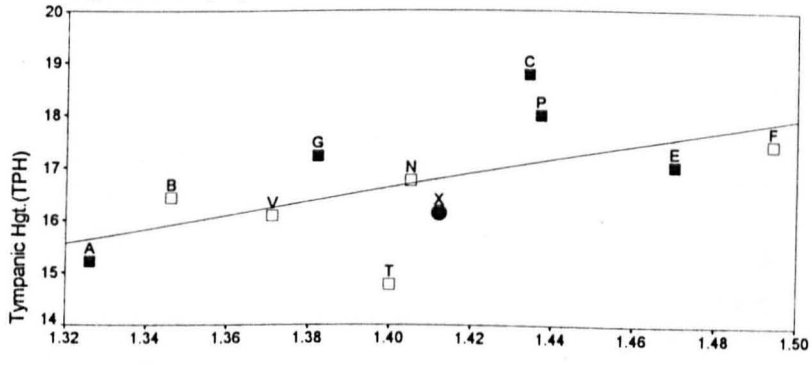


Fig.5.3.13b Tympanic Plate Height vs. Cranial Size



Cranial Size (LBH)

TPH = 13.3 LBH - 1.96; R =.575, p=.064, n=11. (r =.409, p =.000, n=444)

Chi.tympanic plate is tall, that of Tas. short, absolutely & relatively.

Fig.5.3.14a Tympanic Plate Lateral Rim Thickness

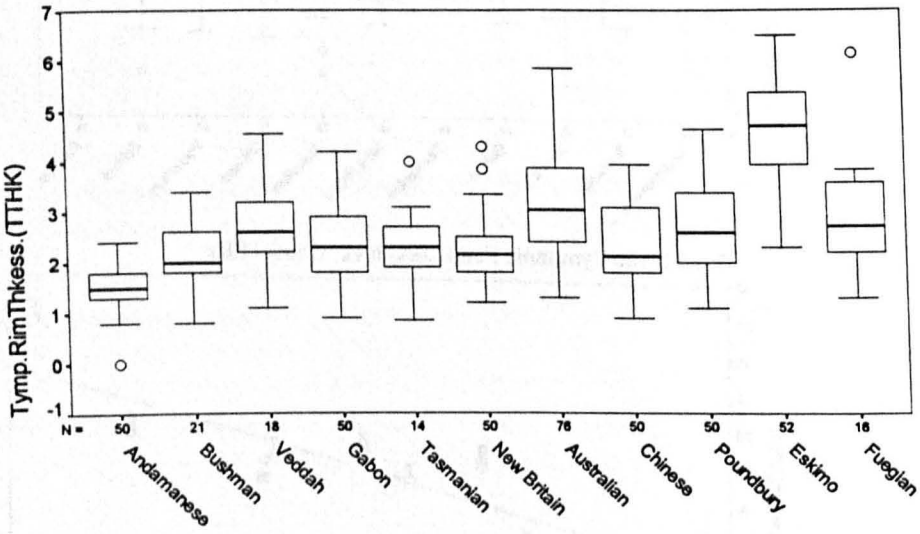
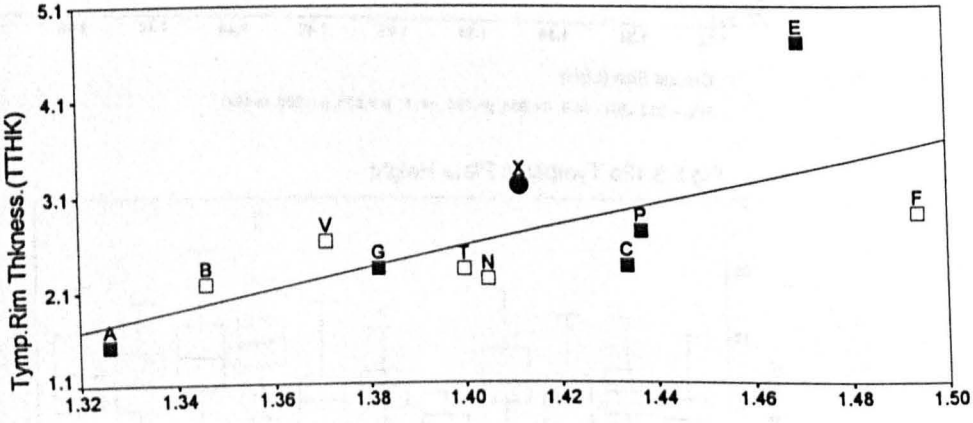


Fig.5.3.14b Tympanic Plate Lat. Rim Thickness vs. Cranial Size

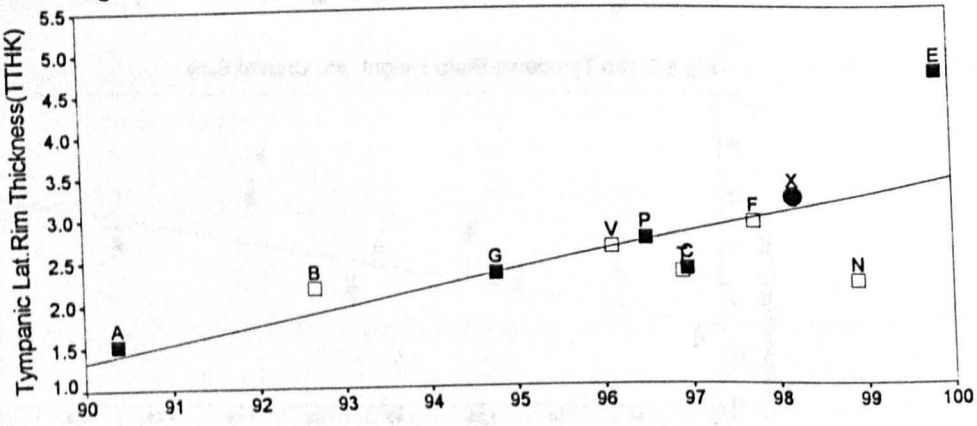


Cranial Size (LBH)

TTHK = 11.1 LBH - 13.0; R =.689, p=.019,n=11. (r =.452, p =.000, n=444)

Eskimo tympanic rim is extremely thick, absolutely and relatively.

Fig.5.3.14c Tympanic Plate Rim Thickness vs. Cranial Breadth Ratio



Cranial Base/Max.Parietal Breadth Ratio(SMC/XCB)

TTHK = .210 SCXCB -17.65, R= .72, p= .013 (r = .42, p = .001)

A thick tympamic rim corresponds to a low maximum cranial breadth.

r=.452, p=.000), and positive and moderate for tympanic plate thickness group means with cranial size group means (r=.689, p=.019; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the lateral rim of Eskimos is particularly thick, that of Australians is moderately thick, and that of Chinese, New Britain, Fuegian and Andamanese is thin (Fig.5.3.14b; see also Plate 8.6 in Ch.8).

The remarkable thickening of the Eskimo tympanic rim has long been recognised (Furst & Hansen 1915:49,50; Oetteking 1927:441; Stewart 1933:481,493). It cannot be explained as the presence of exotoses since that is a very rare condition in Eskimos. Nor is tympanic thickening likely to be a mechanical adaptation since the tympanic rim is neither part of the joint nor offers attachment for muscles (Stewart 1933:491,494). That it cannot be regarded merely as a function of general robusticity was demonstrated by Stewart in a comparison of Eskimo crania with Californian Indian crania; though the crania of the 2 groups are equally massive, the Indian tympanic rim does not approach the thickness of the Eskimo tympanic rim (Stewart 1933:495). Equivalent evidence emerged from this study: New Britain crania are morphologically very similar to Australian crania and in general appearance are at least as robust, but they have a considerably thinner tympanic plate rim than Australians (Fig.5.3.14b).

This study also confirms the findings of Oetteking (1915:30,246) and Stewart (1933:495) that the extreme thickening of the rim has already developed in Eskimo juveniles. This is pictured in the photos of 3 juvenile Eskimo tympanic rims in Plate 5.1 and depicted in the plot of tympanic rim thickness with age and with cranial size in juvenile modern humans (Figs.3.2.9 & 10 in Ch.3). It must be concluded that the thickness of the tympanic rim in Eskimos and the other modern human population groups is an hereditary character and not a pathology nor a mechanical adaptation. This does not necessarily exclude diet as a contributing factor to the condition.

There is a positive association of tympanic rim thickness with the ratio of lower to upper cranial breadth ~~ratio~~, such that the thicker the rim the lower the maximum cranial breadth i.e. the more tent-shaped the cranium (Fig.5.3.14c; see also Fig.6.2.4.3). Eskimos and to less extent, Australians, with

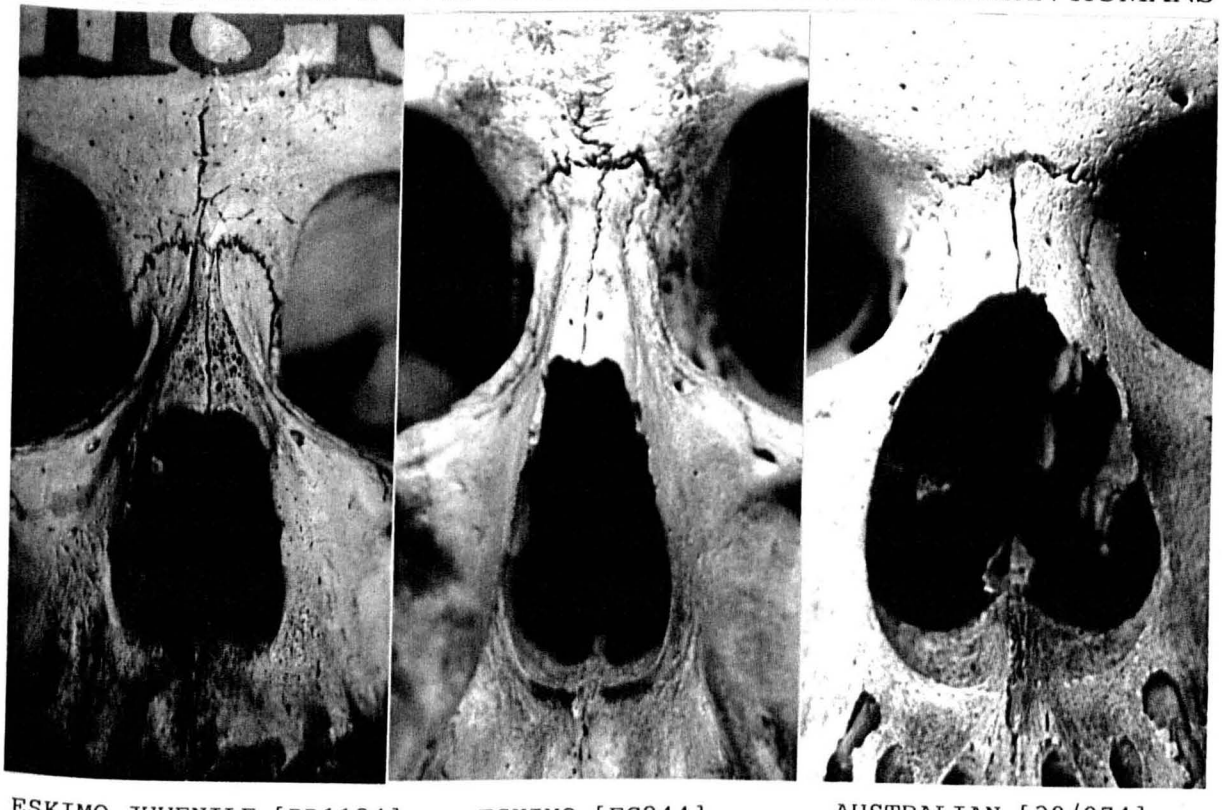
Plate 5.1 TYMPANIC RIM THICKNESS IN JUVENILE ESKIMOS

4.5yrs.ESKIMO '86.4/27/6 7yrs.ESKIMO '86.4/27/5 10yrs.ESKIMO BD1184

The extreme thickness of the Eskimo tympanic plate rim is alredy evident in juvenile Eskimos, indicating it is a hereditary character. The petrosquamosal suture (PS) has not yet been obliterated.

Plate 5.2

NASAL APERTURE WIDTH: EXTREME VARIATION IN MODERN HUMANS



ESKIMO JUVENILE [BD1184] ESKIMO [FC844] AUSTRALIAN [20/974]

The narrowest nasal apertures occur in Eskimos, the widest in Australians. Juvenile Eskimos also have comparatively narrow nasal apertures suggesting the feature is largely hereditary.

thickest rims are the most tent-shaped of modern crania, and Andamanese with thinnest tympanic rims are least tent-shaped. Compared to cranial breadth proportions, the tympanic rim of Eskimos is particularly thick and the New Britain tympanic rim is relatively thin.

5.3.3.15 TYMPANIC PLATE INDENT (TIND). According to absolute value distributions and means (Fig.5.3.14a and Appendix Table A.5.1), the lateral rim of the Fuegian tympanic plate is most indented, that of Gabon and Veddah is least indented (i.e. most protruding). The absolute group means of Fuegian and Chinese are significantly greater than that of Gabon, Veddah and Australian groups, also significantly greater for Fuegian than Eskimos; Gabon and Australian means are significantly less than those of Poundbury, Andamanese, Chinese, Tasmanian and Fuegian (p=.0000).

Correlation of tympanic plate rim indent with cranial size is negligible (r=.050, p=.293); correlation of indent group means with cranial size group means is positive and weak (r=.374, p=.258; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the Fuegian, Tasmanian and Andamanese tympanic rim is deeply indented; that of Gabon, Veddah, Eskimo and Australian groups is protruding (Fig.5.3.15b).

SUMMARY: Correlation of the tympanic plate with cranial size is positive and moderate for length, positive and weak for height and rim thickness, and negligible for rim indent.

The Australian tympanic plate is absolutely quite long and low in height; the protruding lateral rim is very thick absolutely and relatively but not as extreme as that of Eskimos. Notable tympanic plate features of other groups are:
Chinese --- particularly high (absolutely and relatively), well indented and relatively thin;
Andamanese --- particularly thin and deeply indented, absolutely and relatively.
Tasmanian --- low and deeply indented absolutely and relatively.
Fuegian --- relatively thin rimmed, and very long and deeply indented absolutely and relatively.
Eskimo --- protruding and exceptionally thick absolutely and relatively.

Fig.5.3.15a Tympanic Plate Lateral Rim Indent

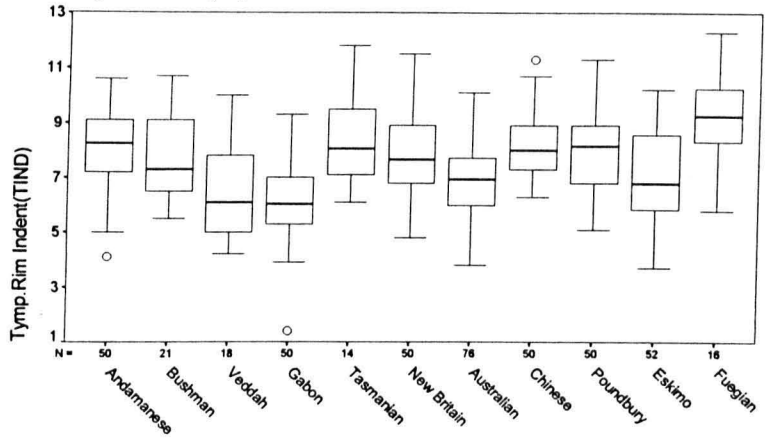
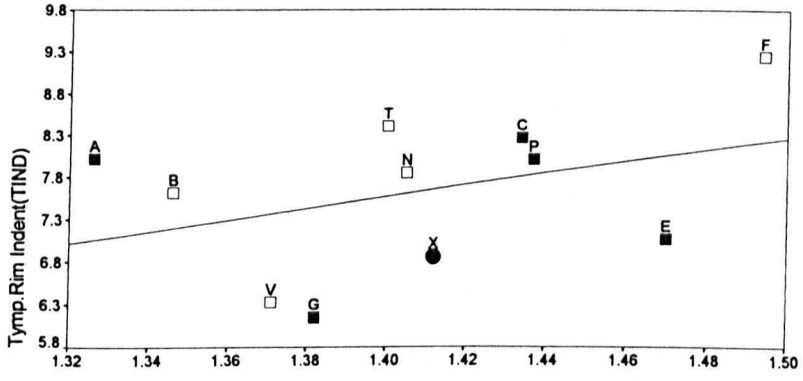


Fig.5.3.15b Tympanic Plate Rim Indent vs. Cranial Size



TIND = 6.94 LBH - 2.14; R =.374, p=.258, n=11. (r =.050, p=.293, n=444)

Fig.5.3.16a Petrous Pyramid Length

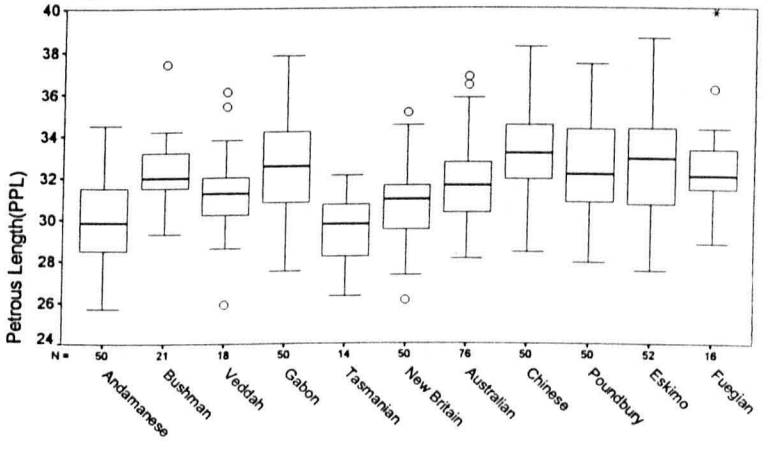
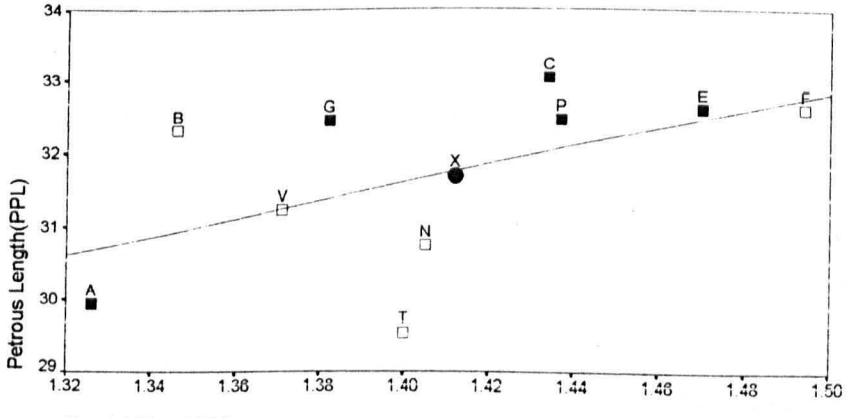


Fig.5.3.16b Petrous Pyramid Length vs. Cranial Size



PPL = 12.6 LBH + 14.0; R =.537, p=.089, n=11. (r =.546, p =.000, n=444)

Fig.5.3.17a Posteriority of Foramen Magnum Centre

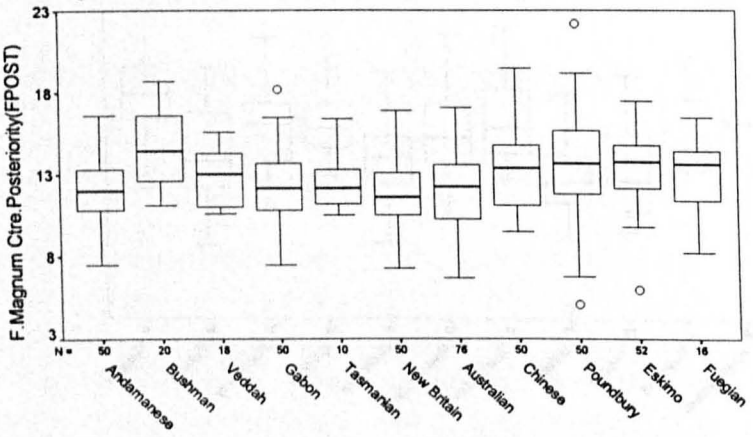
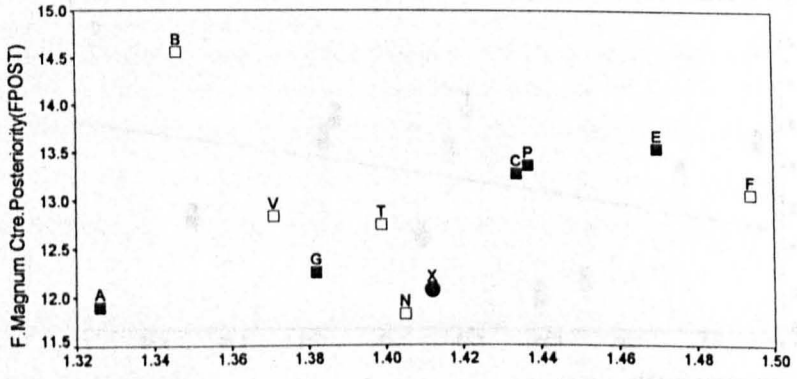


Fig.5.3.17b Posteriority of F.Magnum Centre vs. Cranial Size



FPOST= 2.98 LBH + 8.67; R =.182, p=.593,n=11. (r =.235, p =.000, n=442)

Fig.5.3.18a Anteriority of Basion rel.to Bitympanic Line

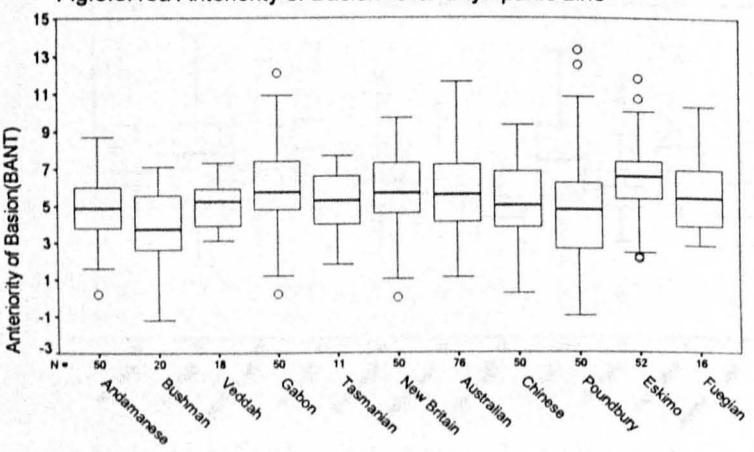
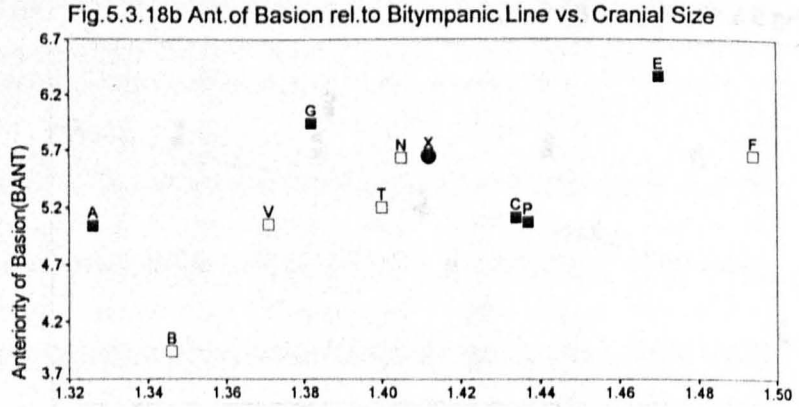


Fig.5.3.18b Ant.of Basion rel.to Bitympanic Line vs. Cranial Size



(r =.116, p =.015, n=442)

5.3.3.16 PETROUS PYRAMID LENGTH (PPL). According to absolute value distributions and means (Fig.5.3.16a and Appendix Table A.5.1), the petrous pyramid of Andamanese and Tasmanian groups is short, that of Chinese is long. The absolute group mean of the Andamanese is significantly smaller than those of all groups except Veddah, Tasmanian and New Britain groups; the Chinese mean is significantly larger than Tasmanian, Andamanese, New Britain and Bushman means (p=.0000).

Correlation is positive and moderate for petrous pyramid length with cranial size (r=.546, p=.000), and for petrous pyramid length group means with cranial size group means (r=.537, p=.089; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the petrous pyramid of Chinese, Gabon and Bushman groups is long, that of New Britain and Andamanese groups is short (Fig.5.3.16b).

5.3.3.17,18 FORAMEN MAGNUM POSITION

5.3.3.17 POSTERIORITY OF FORAMEN MAGNUM CENTRE (relative to the bitympanic line) (FPOS). According to absolute value distributions and means (Fig.5.3.17a and Appendix Table A.5.1), the Bushman centre of the foramen magnum is most posteriorly placed; that of New Britain, Andamanese and Australians is most anterior. There is only one significant difference in absolute group means; the foramen magnum centre is significantly more posteriorly placed for Bushman than for New Britain (p=.0000).

The correlation of foramen magnum centre position with cranial size is positive but very weak (only 5.5% variation accounted for, r=.235, p=.000), and for position group means with cranial size group means is negligible (r=.182, p=.593; Appx.Table A.5.4 and Fig.5.3.17b).

5.3.3.18 ANTERIORITY OF BASION (relative to the bitympanic line) (BANT). According to absolute value distributions and means (Fig.5.3.18a and Appendix Table A.5.1), the basion of Eskimos is positioned most anteriorly, that of Bushman most posteriorly. Analysis of variance found that no significant difference between group means exists at p<.001 (F= 2.64, p=.004, Appx.Table A.5.5).

Correlation of basion anteriority with cranial size is

negligible (r=.116, p=.015), but of basion anteriority group means with cranial size group means it is moderate (r=.582, p=.060; Appendix Table A.5.4 and Fig.5.3.18b).

SUMMARY: Bushman have the most posteriorly positioned foramen magnum, whether measured in terms of the position of basion or of the foramen magnum centre. Australian, New Britain, Gabon, and Andamanese groups have the most anteriorly placed foramen magnum centre; Australian, New Britain, Gabon, Eskimo and Fuegian have the most anteriorly placed basion. The discrepancy can be explained in terms of differences in foramen magnum length; e.g. the exceptionally long foramen magnum of Eskimos is likely to contribute substantially to an anteriorly placed basion even though the foramen magnum centre of this group is comparatively posteriorly positioned. Similarly, an anterior position for both basion and foramen magnum centre in Andamanese is consistent with the very short foramen magnum of Andamanese. Differences between group means for basion position are not significant at p<.001.

Correlation of foramen magnum anteriority with cranial size is negligible in terms of basion position and very weakly positive in terms of the foramen magnum centre, at p<.001.

5.3.3.19-22 ANGLES OF MASTOID PROCESS, SUPRAMEATAL CREST AND EXTERNAL AUDITORY MEATUS

5.3.3.19 MASTOID PROCESS ANGLE (MANG). According to the absolute value distributions and means (Fig.5.3.19a and Appendix Table A.5.1), Andamanese have the most vertically inclined mastoid, Bushman and Australians have the most acutely angled mastoid. The Andamanese absolute mean is significantly greater than that of Australian, Bushman, Poundbury, Eskimo and New Britain groups, and the Australian mean is significantly less than that of Andamanese, Chinese and Gabon at p=.0000.

Correlation is negative and very weak for the mastoid angle with cranial size (only 3.3% of variance accounted for, r=-.182, p=.000), and for mastoid angle group means with cranial size group means (r=-.193, p=.569; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the mastoid process of Australian and Bushman groups is most acutely inclined, that of Andamanese and Chinese is most vertically inclined (Fig.5.3.19b).

Fig.5.3.19a Mastoid Process Axis Angle

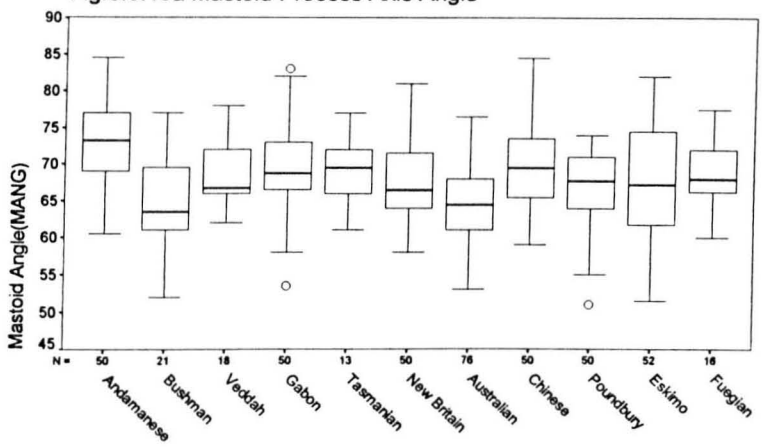
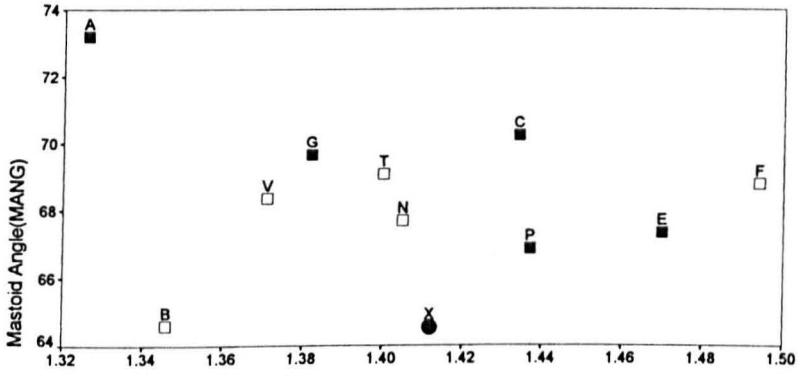


Fig.5.3.19b Mastoid Process Axis Angle vs. Cranial Size



(r =-.182, p =.000,n=444)

Fig.5.3.20a Mastoid Axis/Suprameatal Crest Angle

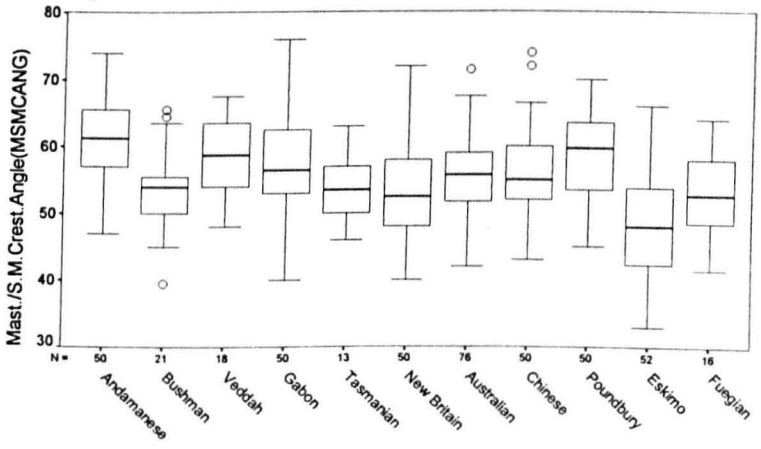
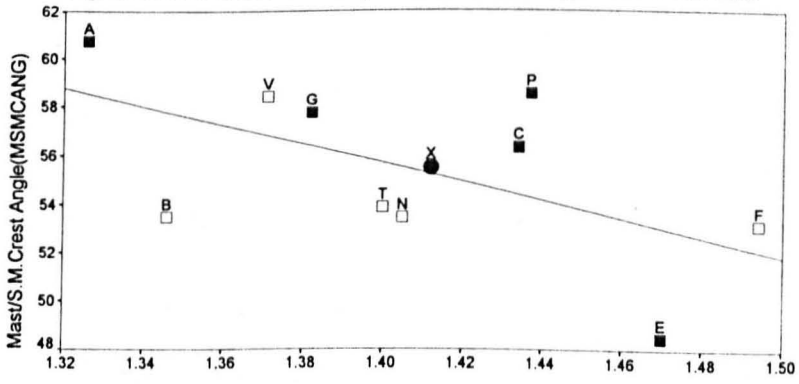


Fig. 5.3.20b Mastoid Axis-Suprameatal Crest Angle vs. Cranial Size



MSMCANG= -38.4 LBH +109.5;R=-.568,p=.068,n=11. (r =-.186, p=.000,n=444)

Fig.5.3.21a Suprameatal Crest Angle

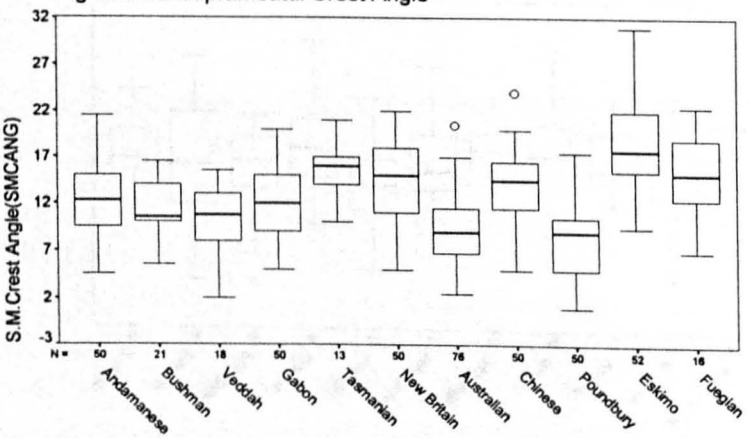
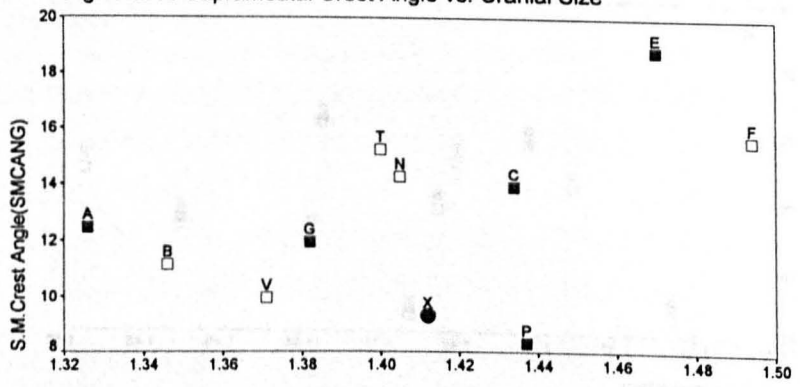


Fig.5.3.21b Suprameatal Crest Angle vs. Cranial Size



SMCANG= 28.9LBH - 27.9; R =.467, p=.147, n=11. (r =.051, p=.283, n=444)

Fig.5.3.22a External Auditory Meatus Axis Angle

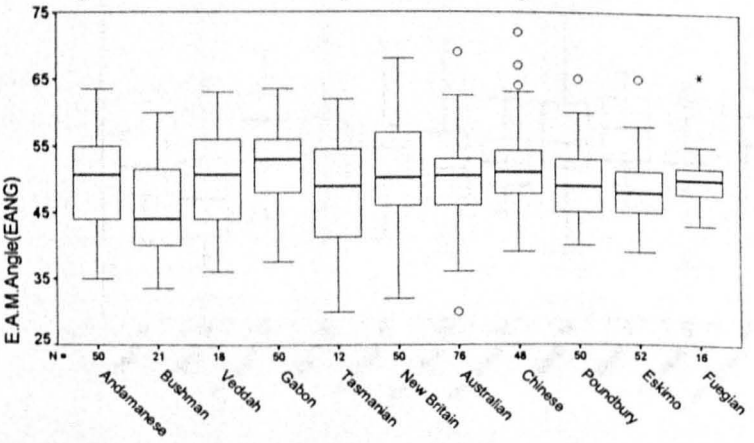
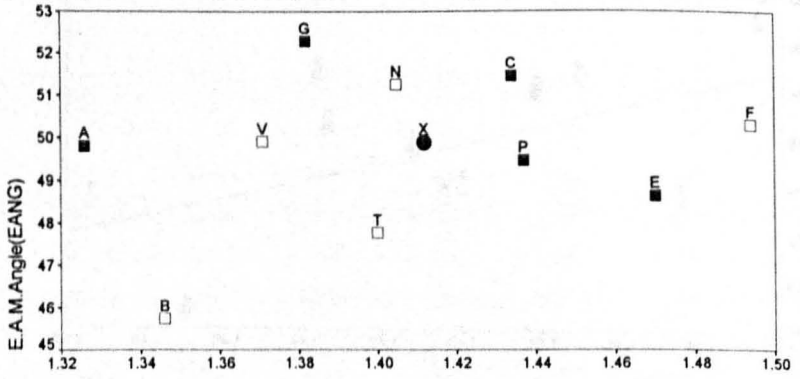


Fig.5.3.22b Ext.Auditory Meatus Axis Angle vs.Cranial Size



EANG= 7.94 LBH + 38.5; R=.219, p=517,n=11. (r =-.040, p=.400, n=441)

5.3.3.20 MASTOID AXIS-SUPRAMEATAL CREST ANGLE (MSCANG). According to the absolute value distributions and means (Fig.5.3.20a and Appendix Table A.5.1), Andamanese and Poundbury have the largest angle between the mastoid axis and the suprameatal crest, Eskimo the smallest. The Eskimo absolute mean is significantly less than that of Australian, Chinese, Gabon, Veddah, Poundbury, and Andamanese groups; the absolute mean of Andamanese is significantly more than that of Eskimo, New Britain and Australian ($p=.0000$).

Correlation of the mastoid/suprameatal crest angle with cranial size is negative and very weak (only 3.5% of variance accounted for, $r=-.186$, $p=.000$), and of the angle group means with cranial size group means is moderate ($r=-.568$, $p=.068$; Appendix Table A.5.4). Compared to other groups and relative to cranial size, the angle is large for Poundbury and small for Eskimo and Bushman (Fig.5.3.20b).

5.3.3.21 SUPRAMEATAL CREST ANGLE (SCANG). According to the absolute value distributions and means (Fig.5.3.21a and Appendix Table A.5.1), the suprameatal crest angle is most acute for Australian and Poundbury groups, and very large for Eskimos. The Eskimo absolute mean is significantly greater than that of all groups except Tasmanian and Fuegian; the Poundbury and Australian means are significantly less than those of Veddah and Bushman ($p=.0000$).

Correlation of the suprameatal crest angle with cranial size is negligible ($r=.051$, $p=.285$), and of the angle group means with cranial size group means is very weak ($r=.467$, $p=.147$; Appendix Table A.5.4, and Fig.5.3.21b).

5.3.3.22 EXTERNAL AUDITORY MEATUS AXIS (EAM) ANGLE (EANG). According to the absolute value distributions and means (Fig.5.3.22a and Appendix Table A.5.1), the Bushman EAM angle is the most acute and that of Gabon the most vertically inclined. No significant difference was found between group means in Oneway Analysis of Variance at $p<.001$ (Appendix Table A.5.5). There is no significant correlation of EAM angle with cranial size nor of the angle group means with cranial size group means at $p<.1$ (Appendix Table A.5.4, and Fig.5.3.22b).

SUMMARY: The correlation with cranial size of mastoid angle and of mastoid/suprameatal crest angle is negative but

very weak; neither suprameatal crest angle nor EAM angle have significant correlation with cranial size at $p<.001$.

Australians and Bushman groups have absolutely and relatively the most acute mastoid angle; Australian and Poundbury groups have the most acute suprameatal crest angle. Andamanese have absolutely and relatively the most vertically inclined mastoid angle and the largest angle between mastoid and suprameatal crest. Eskimos have a particularly large suprameatal crest angle and a small angle between mastoid and suprameatal crest. The EAM angle is largest for Gabon and most acute for Bushman.

5.3.3.23-26 ANGLES OF THE PETROUS AND TYMPANIC AXES

5.3.3.23 ANTERIOR TYMPANIC PLATE SAGITTAL ANGLE (ATANGS). According to the absolute value distributions and means (Fig.5.3.23a and Appendix Table A.5.1), the anterior side of the tympanic plate is most coronally inclined for Eskimos, intermediate for Australians and most sagitally inclined for Chinese. The absolute mean of Eskimos is significantly greater than those of all groups except Tasmanian, Bushman and Gabon; Gabon absolute mean is significantly greater than Chinese, Andamanese and New Britain means; Chinese absolute mean is significantly less than Australian, Bushman, Gabon and Eskimo group means ($p<.0001$, Appendix Table A.5.5).

There is no significant correlation of tympanic anterior angle with cranial size or of the angle group means with cranial size group means ($p<.001$; Appendix Table A.5.4 & Fig.5.3.23b).

5.3.3.24 TYMPANIC AXIS SAGITTAL ANGLE (TANGS). According to the absolute value distributions and means (Fig.5.3.24a and Appendix Table A.5.1), the tympanic plate axis is most sagitally inclined for Veddah and Gabon groups, intermediate for Australians and most coronally inclined for Eskimos. The absolute mean of Eskimos is significantly greater than Veddah, Gabon, Poundbury, Chinese and New Britain group means at $p<.0001$ (Appendix Table A.5.5).

There is no significant correlation of tympanic sagittal angle with cranial size or of the angle group means with cranial size group means at $p<.001$ (Appendix Table A.5.4 & Fig.5.3.24b).

Fig.5.3.23a Tympanic Plate Anterior Sagittal Angle

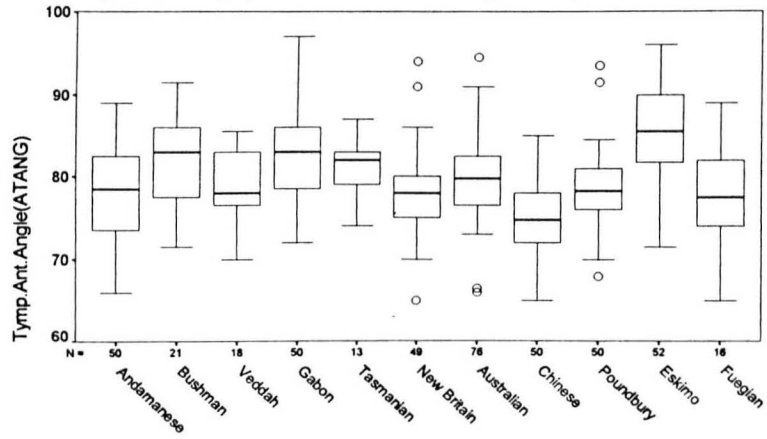
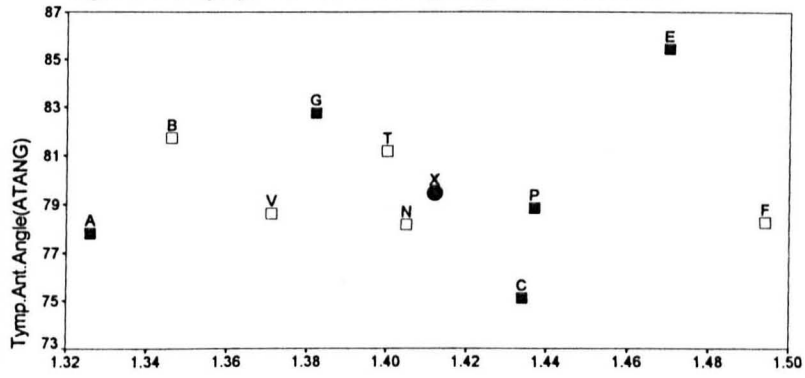


Fig.5.3.23b Tympanic Plate Ant.Sag. Angle vs. Cranial Size



ATANG = 2.45 LBH + 76.3; R=.044,p=.898. (r =.145,p =.002,n=443)

Fig.5.3.24a Tympanic Plate Axis Sagittal Angle

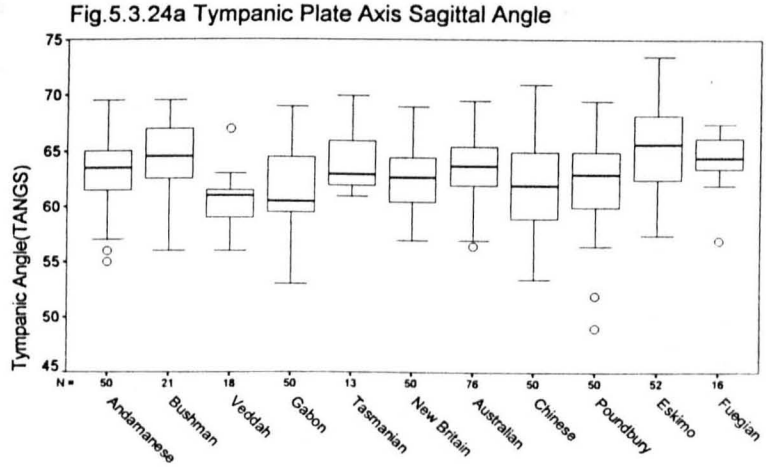
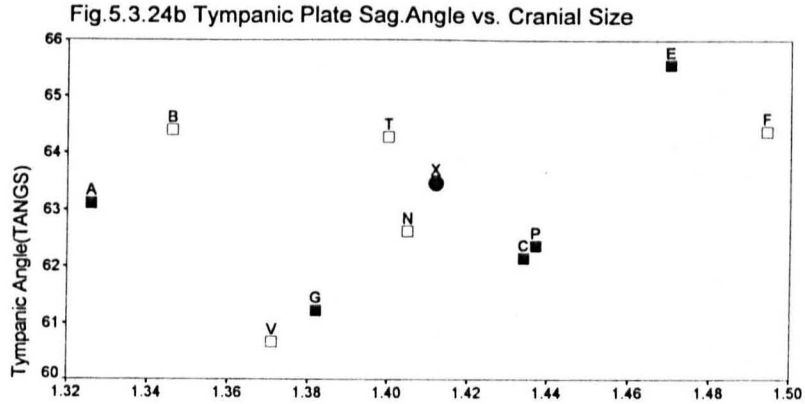


Fig.5.3.24b Tympanic Plate Sag.Angle vs. Cranial Size



TANGS =10.5 LBH + 48.4; R=.356, p=.282, n=11. (r =.126, p =.008, n=444)

Fig.5.3.25a Petrous Pyramid Axis Sagittal Angle

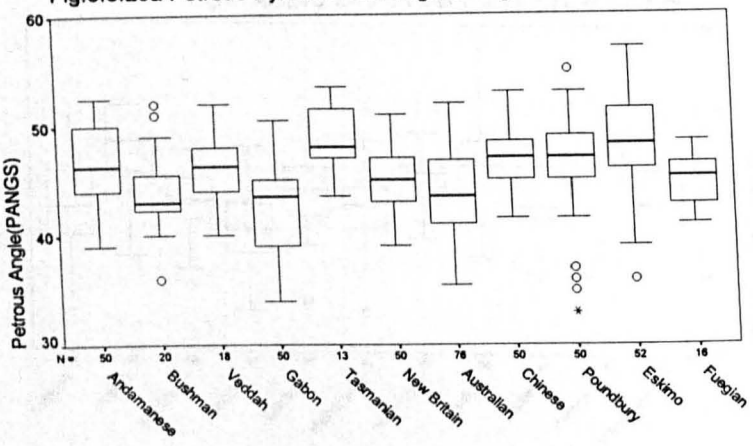
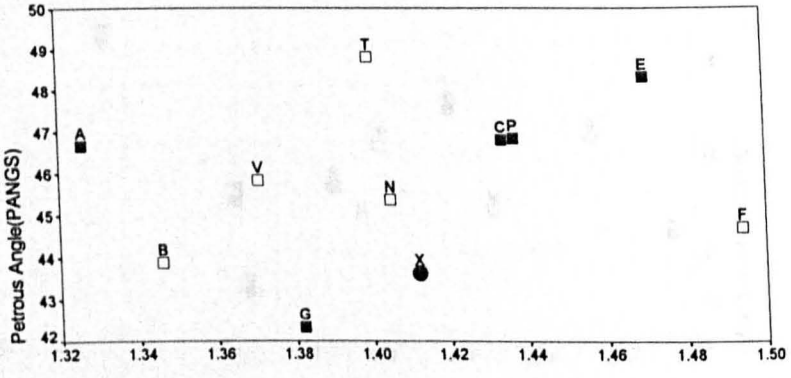


Fig.5.3.25b .Petrous Pyramid Axis Sag.Angle vs. Cranial Size



PANGS = 8.71 LBH + 33.5; R=.220, p=.516,n=11. (r =.144, p =.002, n=443)

Fig.5.3.26a Petrous-Tympanic Axes Angle

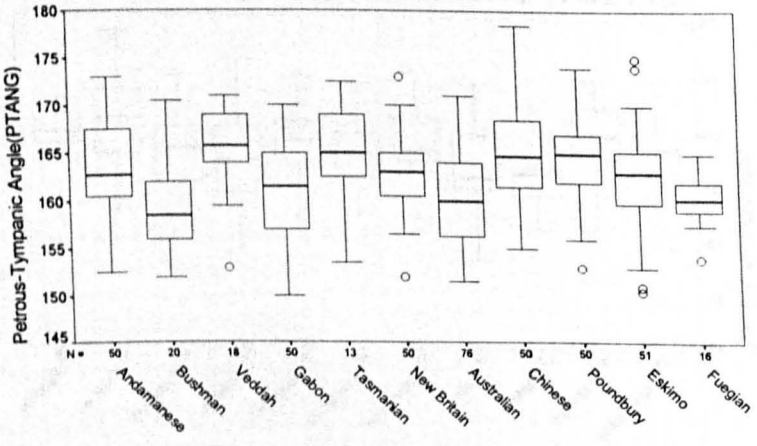
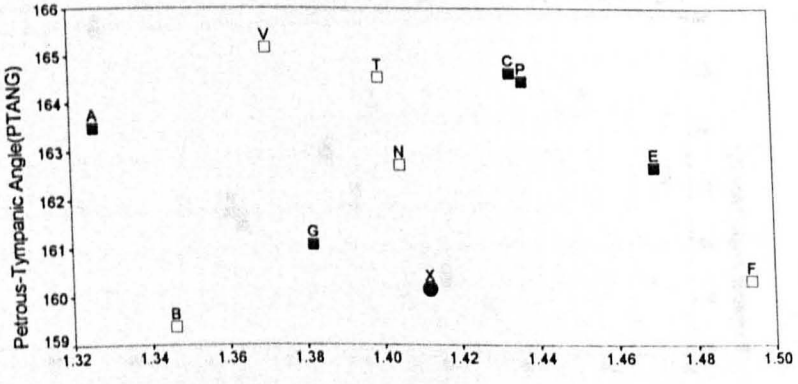


Fig.5.3.26b Petrous-Tympanic Axes Angle vs. Cranial Size



PTANG= -1.46 LBH + 164; R =-.036, p=.917, n=11. (r =.028, p=.564, n=442)

5.3.3.25 PETROUS AXIS SAGITTAL ANGLE (PANGS). According to the absolute value distributions and means (Fig.5.3.25a and Appendix Table A.5.1), the petrous pyramid axis is most sagitally inclined for Gabon, Bushman and Australian groups, and most coronally inclined for Tasmanians and Eskimos. The absolute means of Gabon and Australians are significantly less than Andamanese, Chinese, Poundbury, Eskimo and Tasmanian means at $p<.0001$ (Appendix Table A.5.5).

There is no significant correlation of petrous sagittal angle with cranial size or of petrous angle group means with cranial size group means at $p<.001$ (Appendix Table A.5.4 & Fig.5.3.25b).

5.3.3.26 PETROUS-TYMPANIC ANGLE (PTANG). According to the absolute value distributions and means (Fig.5.3.26a and Appendix Table A.5.1), the angle between the petrous and tympanic axes is most acute for Gabon, Bushman and Australian groups, and largest for Veddah, Chinese, Tasmanians and Poundbury groups. The absolute mean of Australians is significantly less than Chinese and Poundbury means and the Bushman mean is significantly less than that of Chinese at $p<.0001$ (Appendix Table A.5.5).

There no significant correlation of the petrous-tympanic angle with cranial size or of the angle group means with cranial size group means at $p<.001$ (Appendix Table A.5.4 & Fig.5.3.26b).

SUMMARY: No angles involving the petrous pyramid or tympanic plate are significantly correlated with cranial size at $p<.001$. Australians, with Gabon and Bushman, have the most sagitally inclined petrous pyramid and the smallest angle between the petrous and tympanic axes.

The tympanic plate of Eskimos has the most coronally inclined axis and anterior side. With Tasmanians, the Eskimo petrous axis is also the most coronally inclined.

Chinese have the most sagitally inclined tympanic anterior side.

Veddah and Gabon have the most sagitally inclined tympanic plate axis.

Veddah, Tasmanian, Chinese and Poundbury groups have the largest petrous-tympanic angle.

These results largely support and extend the findings of Schulter (1976:453,454,466) in a study involving just three

population groups, Eskimos, Amerindian and American Caucasian. Schulter detected strong variation between the groups in petrous sagittal angle and petrous tympanic angle which would consequently be effective criteria for differentiating populations. She found Eskimos have significantly smaller petrous-tympanic and petrous sagittal angles than the other 2 groups. Considering the results in this study for just Eskimos and, in place of the Amerindian and American Caucasian groups, Chinese and Poundbury, there is agreement about the petrous-tympanic angle, but not about the petrous sagittal angle; the present study found that Eskimos have a particularly large petrous sagittal angle. Schulter's conclusion that petrous sagittal angle and petrous-tympanic angle are independent of other cranial variables such as overall cranial length, height, biauricular breadth and maximum cranial breadth, coincide with the findings in this study that petrous and petrous-tympanic angles are no more than weakly correlated at $p<.001$ with the cranial size or overall cranial dimensions (Appendix Tables A.5.2 & 4).

5.3.4

SUMMARY OF BETWEEN-GROUPS VARIATION FOR 26 TEMPORAL VARIABLES

5.3.4.1 CORRELATION OF TEMPORAL VARIABLES WITH CRANIAL SIZE

(i) All but two of the 17 linear temporal variables have significant positive correlation with cranial size at $p<.001$; the correlation strength varies from moderate to very weak.

(ii) 2 of the angular temporal variables (mastoid angle and mastoid-suprameatal crest angle) have significant but very weak negative correlation with cranial size. All other non-linear temporal variables have negligible correlation with cranial size at $p<.001$.

(iii) No group's mean cranial size differs significantly from all other 10 population groups. Andamanese mean cranial size is significantly smaller than that of the other 5 regionally distinct groups.

(iv) Australian crania are intermediate in overall size. The Australian mean cranial size is significantly smaller than Fuegian and Eskimo means and significantly larger than Andamanese and Bushman means.

5.3.4.2 SIGNIFICANT DIFFERENCES IN ABSOLUTE GROUP MEANS OF TEMPORAL VARIABLES

(v) Significant difference between group means exists for all temporal variables except two, anteriority of basion and the external auditory meatus (EAM) angle at $p<.001$.

(vi) Groups with larger crania tend to have significantly larger mean values for linear temporal variables than other groups. The same trend is not apparent if the temporal variables concerned are angular. This is consistent with linear temporal variables having some dependence on cranial size, and non-linear temporal variables being independent of cranial size.

(vii) Australian and Eskimo groups differ significantly from other groups in angular temporal measurements notably more often than do other groups; Australians tend to have significantly more acute angles than other groups, Eskimos tend to have significantly larger angles than other groups.

(viii) Andamanese differ significantly in linear temporal measurements, and in temporal measurements in general, more often than do other groups.

(ix) The only temporal variables for which a group's absolute mean value differs significantly from the means of the other 10 groups are:

(1) The Eskimo tympanic plate rim is thicker

(2) The Fuegian tympanic plate is longer .

(x) Considering only the 6 large sample, regionally distinct population groups, the temporal variables for which a group's absolute mean value differs significantly from the means of the other 5 groups are:

(1) The Andamanese petrous pyramid is shorter.

(2) The Andamanese tympanic plate rim is thinner.

(3) The Eskimo tympanic plate rim is thicker.

(4) The Eskimo suprameatal crest angle is larger.

(5) The Eskimo mastoid-suprameatal crest angle is smaller (Appendix Table A.5.6.4).

(xi) For no temporal variable did the Australian absolute mean differ significantly from that of all other 10 groups or from the other 5 large sample, regionally distinct groups (Appendix Table A.5.6.4).

5.3.4.3 AUSTRALIAN TEMPORAL CHARACTERISTICS

(xii) Based on absolute values and on means relative to cranial size group means, Australian crania are characterised by the following temporal features:

(1) a glenoid fossa which is intermediate in depth, volume and length/width ratio, and relative to cranial size is long, wide and large in area.

(2) a low temporal squamous. (From the absolute means, the Australian temporal squamous is the lowest relative to cranial size of the 6 core groups; when all 11 groups are considered, 3 others are as low or lower relatively and absolutely.)

(3) a mastoid process which is relatively and absolutely long and very deep, somewhat narrow, intermediate in volume and inclined at an acute angle.

(4) an acute suprameatal crest angle.

(5) a petrous pyramid which is sagitally inclined and intermediate in length;

(6) a small petrous-tympanic angle.

(7) a low, quite long tympanic plate with a lateral rim which is protruding and thicker than that of all groups except Eskimos.

5.4 NON-TEMPORAL VARIABLES

5.4.1 CORRELATION WITH CRANIAL SIZE (Appendix Table A.5.7) All linear non-temporal variables except 3 show significant positive correlation with cranial size at $p<.001$. The strength of the associations varied from strong to very weak. The highest correlation is for biauricular breadth ($r=.874$, $p=.000$) and accounts for 76.4% of the variation; the lowest significant correlation is for nasal aperture width ($r=.193$, $p=.000$) and accounts for merely 3.7% of the variation.

Four variables show negative, though weak correlation with cranial size. One of these variables is linear (endinion-inion separation), one is angular (base angle) and two are ratios (nasal width/height, and occipital chord/ arc).

Five variables show no correlation with cranial size at $p<.001$. Two of these variables are linear (endinion-opisthion chord and opisthocranion-inion arc), one is angular (foramen magnum angle), and two are ratios (cranial breadth/length and lambda-inion chord/opisthion-inion chord).

5.4.2

SIGNIFICANT DIFFERENCES BETWEEN GROUPS IN ABSOLUTE MEANS.

One-way Analysis of Variance found that of the 29 non-temporal variables there is significant difference between group absolute means for all but endinion-opisthion chord at $p<.0001$ (Appendix Table A.5.5).

Scheffe's test identified the groups between which significant differences in means occurs for a particular variable. Appendix Tables A.5.8.1-3 record the number of times each group differs significantly in absolute means from another group. In Appendix Table A.5.8.1, each number corresponds to the number of linear non-temporal variables which are significantly greater for the vertically listed group than for the corresponding horizontally named group. e.g. Australians have significantly greater mean values than do Bushman in 8 linear non-temporal variables. Each number also corresponds to the number of linear non-temporal variables which are significantly smaller for the horizontally named group than for the vertically listed group. e.g. Australians have significantly smaller mean values than do

Poundbury in 5 linear non-temporal variables.

In the same way, Appendix Table A.5.8.2 records the number of significant differences in group means of 7 non-linear non-temporal variables. In both tables, the groups are ordered according to increasing cranial size from left to right and from top to bottom. Thus it can be seen from Table 9 that groups associated with larger crania tend to have a greater number of linear non-temporal variables with group mean values significantly higher than those of other groups.

No such tendency is evident in the results in Appendix Table A.5.8.2 for non-linear non-temporal variables.

A quantitative estimate of which groups differ most can be made from Appendix Table A.5.8.3 in which the total number of significant differences in means for each group is recorded.

SUMMARY:(Appendix Table A.5.8.3). There is a tendency for groups with larger crania to have larger mean values for linear non-temporal variables than those of other groups. This tendency is more pronounced than it was for linear temporal variables (Appendix Table A.5.6.4) and is not true in general for non-linear (angular and ratio) variables, temporal or non-temporal.

As was the case for temporal variables, of the 11 population groups, Andamanese show the greatest number (154) of significant differences in non-temporal variable means, Tasmanian (38) and Veddah (66) the least. In interpreting these results, the relatively small sample size of the Tasmanians should be taken into consideration.

When the 6 regionally distinct population groups only are considered, according to the number of significant differences in means:

(i) for <u>linear</u> variables, non-temporal or temporal, Gabon and Australian groups are least different. This is consistent with the intermediate magnitude of Australian and Gabon linear cranial dimensions and association of linear variables in general with cranial size.

(ii) for <u>non-linear</u> variables, Australians are least different of the 6 groups if the variables are non-temporal, but with Eskimos are most different if the variables are temporal. That is, Australians differ significantly from the other 5 core groups more in temporal than in non-temporal variables.

5.4.3 BETWEEN-GROUPS VARIATION FOR EACH NON-TEMPORAL VARIABLE

The same aspects of variation considered for temporal variables are discussed for 29 non-temporal variables.

5.4.3.1-7 CRANIAL BREADTH DIMENSIONS

Of the 7 variables measuring cranial breadth, BIAURICULAR, BIZYGOMATIC and BISUPRAMASTOID CREST BREADTHS are strongly correlated with cranial size ($r > .830$, $p = .000$ for all three; Appendix Table A.5.7). This is evident from the group absolute means (Appendix Table A.5.1) and the boxplots (Figs.5.4.1a-3a) which show that the absolute means of the 3 different breadth variables are largest for Fuegian, then for Eskimo, Poundbury and Chinese, and smallest for the 4 groups associated with the smallest crania, Andamanese, Bushman, Veddah and Gabon. Australian, New Britain and Tasmanian absolute breadth means are intermediate. Fuegian ZYB and AUB absolute means are significantly larger than those of all other groups except Eskimos ($p = .0000$).

The correlation of group means of these 3 variables with cranial size group means is very high ($r > .920$, $p = .000$ for all three; Appendix Table A.5.7 & Figs.5.4.1b-3b). However, within that general trend a few variations occur:

5.4.3.1 BIAURICULAR BREADTH (AUB). Compared to other groups and relative to cranial size, Australian, Eskimo, Gabon and Veddah biauricular breadth group means are small, those of Tasmanians, Chinese, Fuegians and Andamanese are relatively large (Fig.5.4.1b). On the basis of its analysis of variance F ratio, Howells (1969:453) regarded biauricular breadth as the most effective single measurement in discriminating modern human populations. In this study also, biauricular breadth has the highest F ratio of any variable, temporal or non-temporal (Appendix Tables A.5.7 (& 4)).

5.4.3.2 BISUPRAMASTOID CREST BREADTH (SCB). Compared to other groups and relative to cranial size, Australian, Eskimo and Veddah group means are small, those of Poundbury, and to less extent, Chinese, Tasmanians and Bushman are relatively large (Fig.5.4.2b).

5.4.3.3 BIZYGOMATIC BREADTH (ZYB). Compared to other groups and relative to cranial size, Australian, New Britain, Fuegian and Andamanese group means are large, those of Veddah and

Fig.5.4.1a Biauricular Breadth

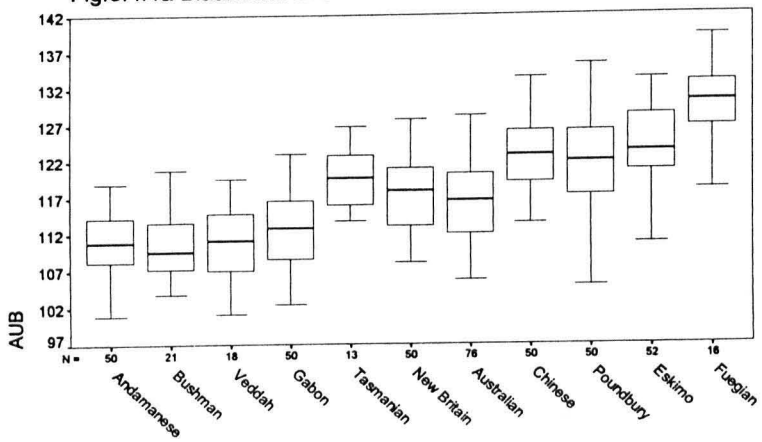
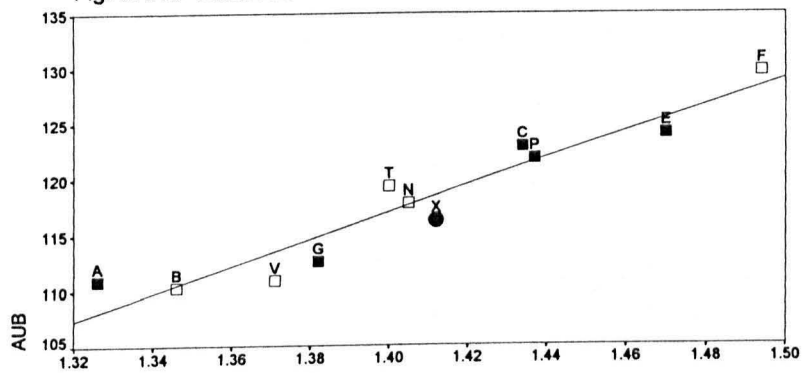


Fig. 5.4.1b Biauricular Breadth vs. Cranial Size



Cranial Size (LBH)

AUB = 119.7LBH - 50.6; R=.952, p =.000, n=11. (r =.874, p =.000, n=444)

Fig.5.4.2a Bisupramastoid Crest Breadth

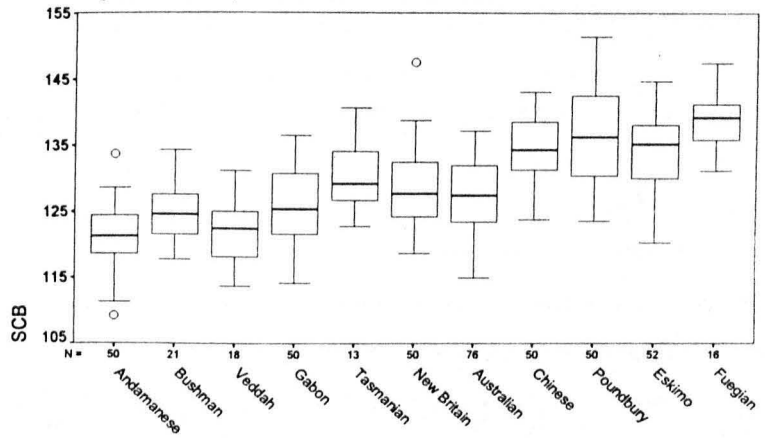
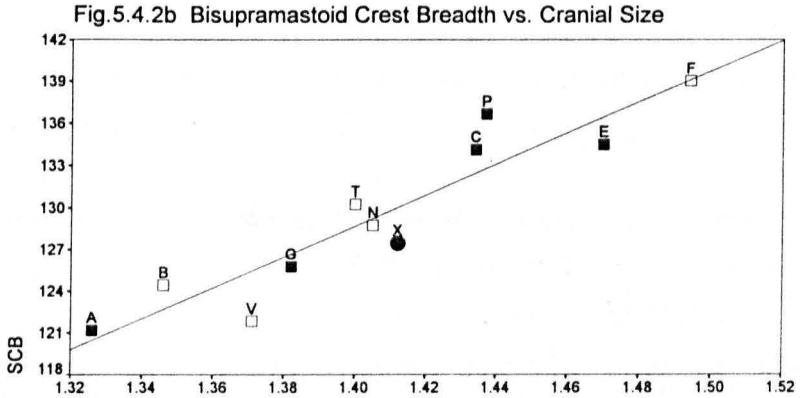


Fig.5.4.2b Bisupramastoid Crest Breadth vs. Cranial Size



Cranial Size (LBH)

SCB = 110.7 LBH - 26.3; R =.930, p=.000, n=11. (r =.832, p =.000, n=444)

Fig.5.4.3a Bizygomatic Breadth

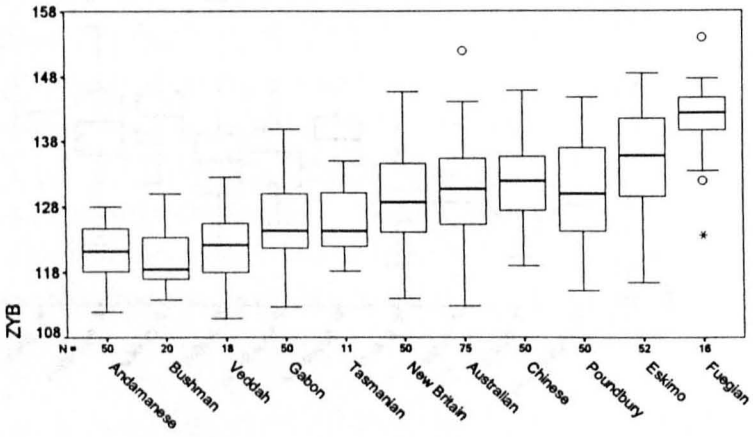
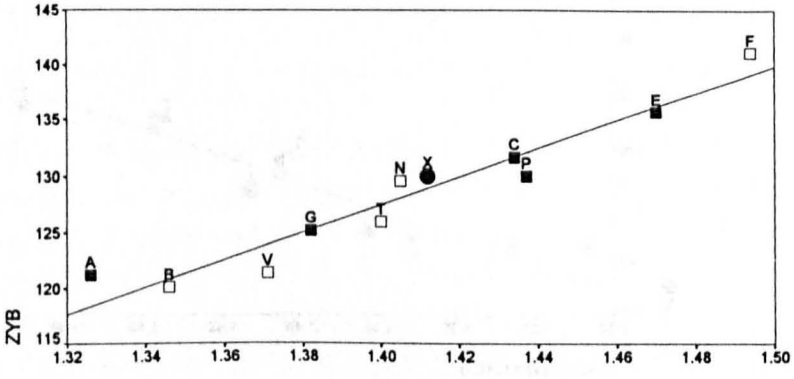


Fig.5.4.3b Bizygomatic Breadth vs. Cranial Size



ZYB = 123.9 LBH - 46.0; R =.965, p=.000, n=11. (r =.869, p =.000, n=442)

Fig.5.4.4a Biasterion Breadth

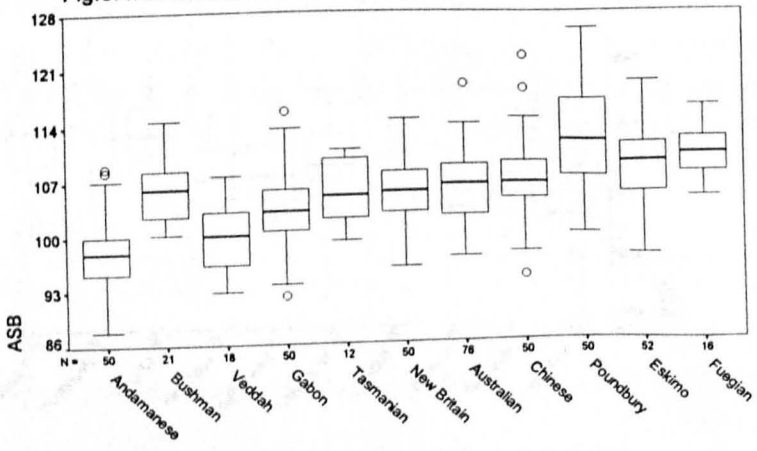
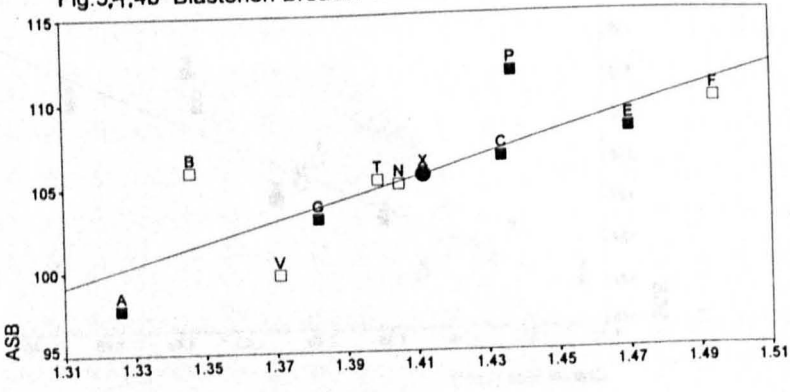


Fig.5,4.4b Biasterion Breadth vs. Cranial Size



ASB = 63.7 LBH + 15.6; R=.797, p =.003, n=11. (r =.705, p =.000, n=444)

Poundbury are relatively small (Fig.5.4.3b).

The remaining 4 cranial breadth variables showed less association with cranial size.

5.4.3.4 BIASTERION BREADTH (ASB). According to absolute value distributions and means (Fig.5.4.4a and Appendix Table A.5.1), Poundbury are broadest at asterion, Andamanese are narrowest and Australian, New Britain and Tasmanian are intermediate. The Poundbury absolute group mean is significantly greater than that of all other groups except Fuegian and Eskimo; the Andamanese mean is significantly less than all except that of Veddah (p=.0000).

Correlation is positive and quite high with cranial size and with cranial size group means (Appendix Table A.5.7). Compared to other groups and relative to cranial size, Bushman and Poundbury crania are particularly broad at asterion, Veddah and Andamanese are relatively narrow (Fig.5.4.4b).

5.4.3.5 MAXIMUM PARIETAL BREADTH (XCB). According to absolute value distributions and means (Fig.5.4.5a and Appendix Table A.5.1), Poundbury and Fuegians are broadest across the parietals, Veddah, New Britain and Australians are narrowest. The Poundbury and Fuegian absolute means are significantly greater than those of all other groups except Chinese; the Australian and Veddah means are significantly less than those of all other groups except New Britain and Gabon (p=.0000).

Correlation is moderate for parietal breadth with cranial size (r =.551, p=.000), and for XCB group means with cranial size group means (R =.558, p=.074; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Australian, Veddah, New Britain and Eskimo groups are narrow across the parietals; Andamanese, Bushman, Fuegian, Poundbury, and Chinese are relatively broad (Fig.5.4.5b).

5.4.3.6 MINIMUM CRANIAL BREADTH (WCB). According to group absolute value distributions and means, Chinese and Fuegian minimum cranial breadth is the largest, that of Tasmanians, New Britain, Andamanese and Gabon groups the smallest (Fig.5.4.6a and Appendix Table A.5.1). The Chinese absolute mean is significantly greater than that of 5 other groups;

Fig.5.4.5a Maximum Parietal Breadth

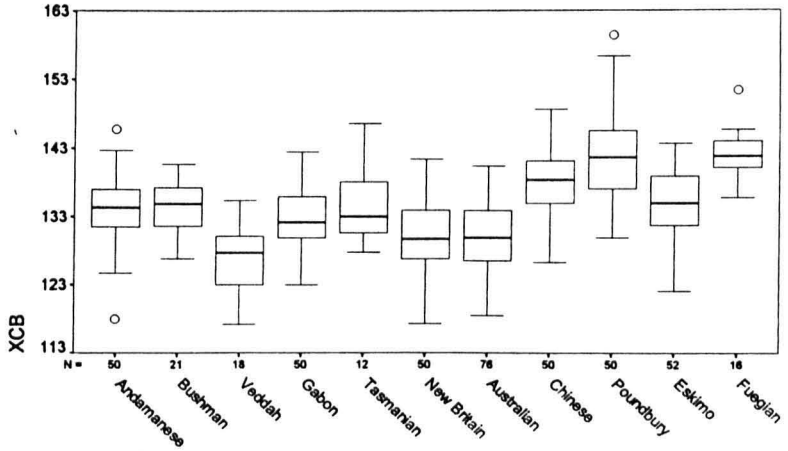
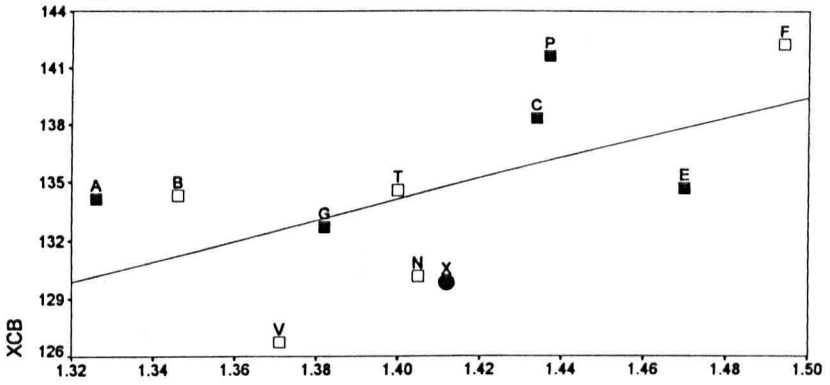


Fig.5.4.5b Max. Parietal Breadth vs. Cranial Size



Cranial Size (LBH)

XCB = 53.0 LBH + 60.0; R=.558, p =.074, n=11. (r =.551, p =.000, n=444)

Fig.5.4.6a Minimum Cranial Breadth

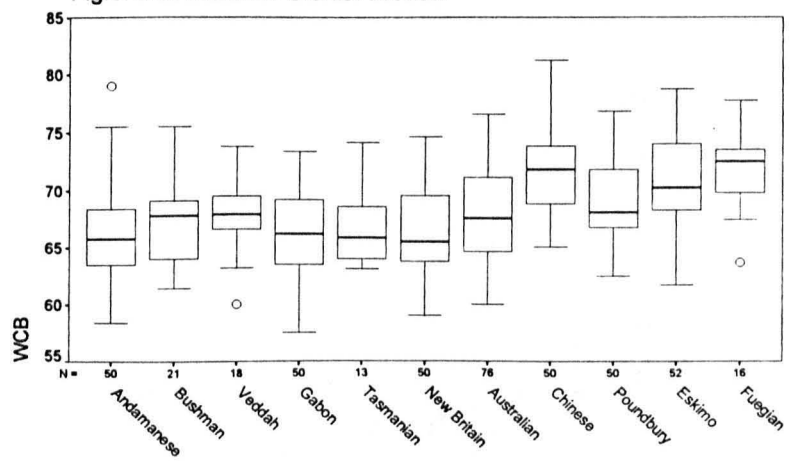
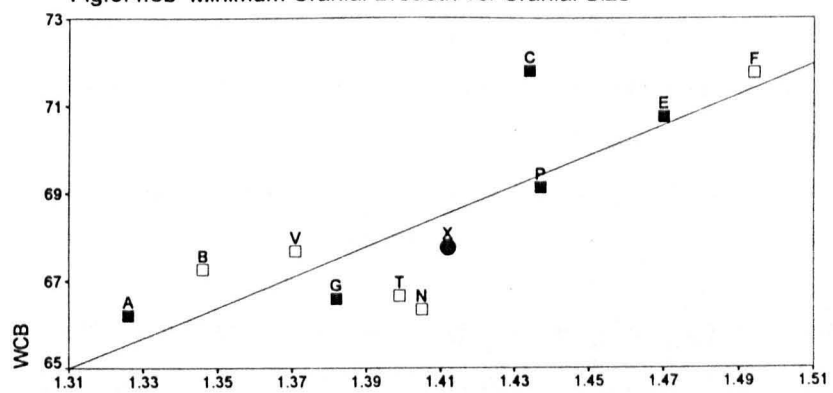


Fig.5.4.6b Minimum Cranial Breadth vs. Cranial Size



Cranial Size(LBH)

AUB = 34.7LBH + 19.6; R=.816, p =.002, n=11. (r =.599, p =.000, n=444)

Fig.5.4.7a Bisupramastoid Crest Breadth/Parietal Breadth Ratio

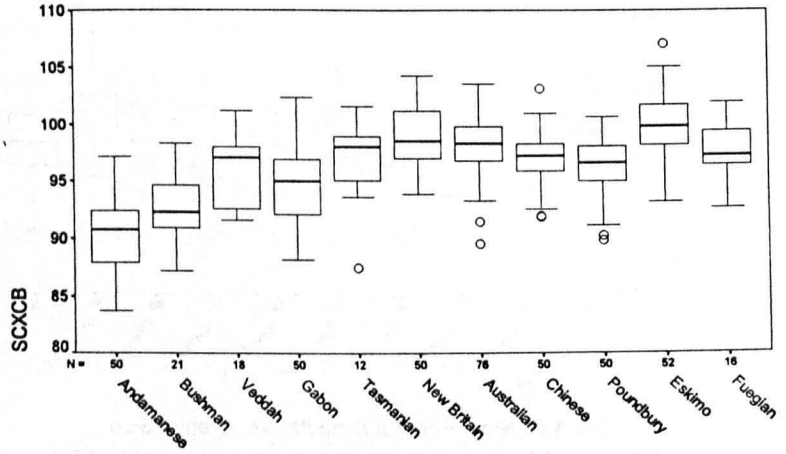
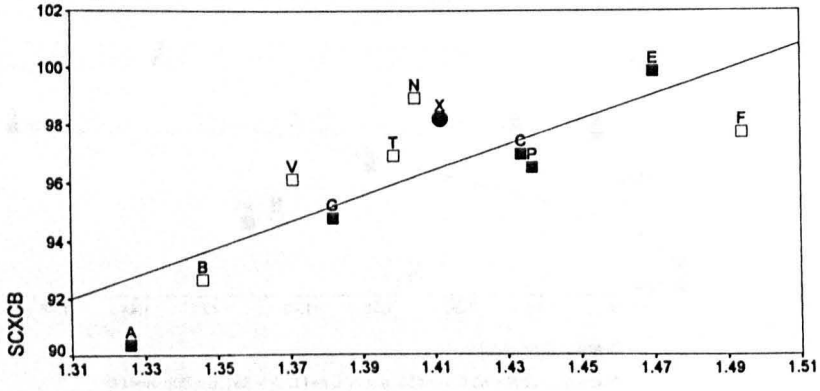


Fig.5.4.7b S.C.Breadth/X.C.Breadth Ratio vs. Cranial Size



Cranial Size(LBH)

SCXCB= 43.9 LBH + 34.5; R =.801, p=.003, n=11. (r =.559, p =.000, n=444)

Fig.5.4.8a Cranial Length (Glabella-Opisthocranion)

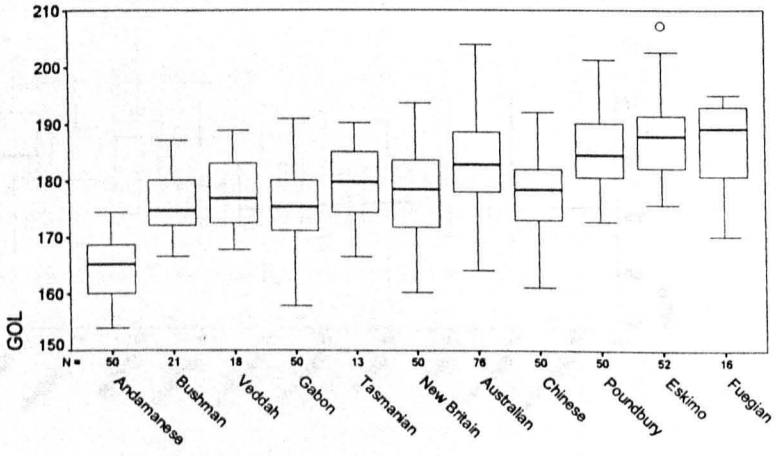
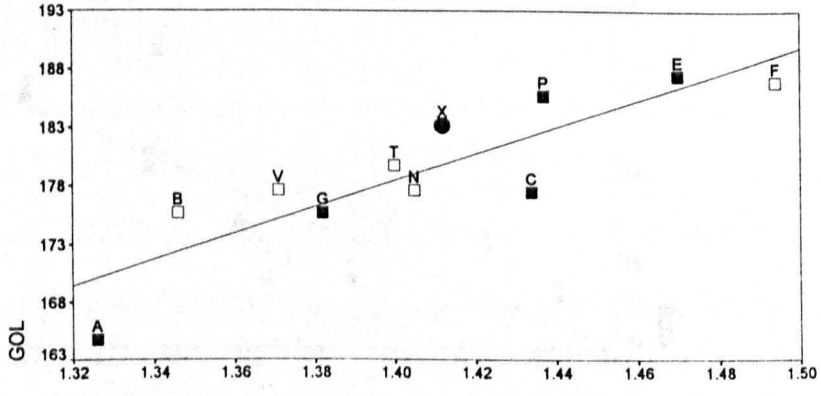


Fig.5.4.8b Cranial Length(GOL) vs. Cranial Size



Cranial Size (LBH)

GOL=113.6 LBH + 19.4; R =.876, p =.000, n=11. (r =.862, p =.000, n=444)

Andamanese, New Britain and Gabon means are significantly less than those of 3 other groups (p=.0000).

Correlation is moderate for min. cranial breadth with cranial size (r =.599, p=.000), and quite strong for WCB group means with cranial size group means (R =.816, p=.002; Appendix Table A.5.7. Compared to other groups and relative to cranial size, the minimum cranial breadth of Australian, New Britain, Tasmanian and Gabon groups is small; that of Chinese is relatively very large (Fig.5.4.6b).

5.4.3.7 SUPRAMASTOID CREST BREADTH/MAX.PARIETAL BREADTH RATIO (SCXCB). The higher the value of the ratio, the broader the cranium is towards the base compared to across the parietals. According to group absolute value distributions and means, Eskimo, Australian and New Britain groups have the highest ratios and Andamanese and Bushman the lowest (Fig.5.4.7a and Appendix Table A.5.1). This is consistent with the tendency of many Eskimo, Australian and New Britain crania to be slightly tent-shaped, and with the prevalence of pronounced parietal bosses in Andamanese and Bushman crania. Of the absolute means, that of Eskimos is significantly greater than that of all other groups except Australian, New Britain and Fuegian; Australian and New Britain means are significantly greater than those of 4 other groups; the Andamanese mean is significantly less than all except Bushman mean, which in turn is significantly less than all except Andamanese, Gabon and Veddah (p=.0000).

Correlation of the ratio with cranial size is moderate and positive (r =.559, p=.000), and quite strong for ratio group means with cranial size group means (R =.801, p=.003; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Australian, New Britain, Tasmanian Veddah and Eskimo crania are broad towards the base, Andamanese and Fuegians are relatively broader on the parietals (Fig.5.4.7b).

SUMMARY: Since bizygomatic and bisupramastoid crest breadths are highly correlated with biauricular breadth which is a component variable of cranial size as defined, all 3 are highly correlated with cranial size. The moderate correlation of biasterionic, maximum parietal and minimum cranial breadths with cranial size reflects their lower correlation with biauricular breadth. Moderate positive correlation of the

cranial breadth
ratio with cranial size is consistent with small crania being associated with parietal bosses, considered by some as an infant-like/female-like characteristic (Frazer 1920:271), and crania with broad base compared to parietal breadth tending to be large and perhaps robust.

Relative to cranial size and compared to other groups, the Australian cranium is intermediate in biasterionic breadth, has a wide zygomatic arch but, according to the other 4 cranial breadths, is narrow. Australians, with New Britain and Eskimo are relatively and absolutely broad at the base compared to across the parietals. The low base to parietal breadth ratio of Andamanese and Bushman reflects the pronounced parietal bosses seen in crania of those two groups.

5.4.3.8-11 CRANIAL LENGTH DIMENSIONS

5.4.3.8 GLABELLA-OPISTHOCRANION LENGTH (GOL). Group absolute value distributions and means show that Fuegian, Eskimo, Poundbury and Australian crania are the longest, and Andamanese is very short (Fig.5.4.8a and Appendix Table A.5.1). The 4 largest absolute means are significantly greater than all others except those of Tasmanians and Veddah; Andamanese absolute mean is significantly smaller than all others (p=.0000).

Correlation is strong for cranial length with cranial size (r =.876, p=.000), and for length group means with cranial size group means (R =.862, p=.000; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Australian, Poundbury, Bushman and Veddah crania are long, Chinese and Andamanese are short (Fig.5.4.8b).

5.4.3.9 FRONTAL ARC (FRA). Group absolute value distributions and means show that frontal arc is longest for Fuegian, Eskimo, Poundbury, Australian and Bushman groups, and very short for Andamanese (Fig.5.4.9a and Appendix Table A.5.1). The Andamanese absolute mean is significantly less than all but three other group means, the New Britain mean is significantly less than Australian, Poundbury and Eskimo means, and the Eskimo mean is significantly greater than Andamanese, New Britain and Gabon means at p=.0000.

Correlation is moderate for frontal arc with cranial size (r =.642, p=.000), and for arc group means with cranial size

group means (R =.577, p=.063; Appendix Table A.5.7). Compared to other groups and relative to cranial size, the frontal arcs of Bushman, Australian, Poundbury, Eskimo and Veddah are long, those of Andamanese, New Britain, Chinese and Tasmanians are short (Fig.5.4.9b). Frontal arc variation corresponds closely but not exactly to cranial length variation.

5.4.3.10 PARIETAL ARC (PAA). Group absolute value distributions and means show that parietal arc is longest for Eskimos, and shortest for Andamanese and Bushman (Fig.5.4.10a and Appendix Table A.5.1). Andamanese and Bushman absolute means are significantly less than those of Eskimo, Poundbury, Australian, New Britain, and Chinese means at p=.0000. The Gabon range of absolute values is particularly large.

Correlation is moderate for parietal arc with cranial size (r =.621, p=.000), and for arc group means with cranial size group means (R =.707, p=.015; Appendix Table A.5.7). The 11 groups divide in two on the basis of parietal arc length relative to cranial size; Fuegian, Bushman, Tasmanian and Andamanese have relatively short parietal arcs (Fig.5.4.10b).

5.4.3.11 BISUPRAMASTOID CREST BREADTH/GLABELLA-OPISTHOCRANION LENGTH RATIO (SCBGOL). Group absolute value distributions and means show that cranial breadth to length ratio is largest for Chinese, Fuegian, Andamanese and Poundbury (i.e. crania from these groups tend to be broad compared to their length); and smallest for Veddah, Australians and Eskimos (crania which are narrow compared to length) (Fig.5.4.11a and Appendix Table A.5.1). The Chinese absolute mean is significantly greater than all but Fuegian, Poundbury and Andamanese means; Australian and Veddah means are significantly less than all except Bushman, Gabon and Tasmanian means (p=.0000).

There is no correlation with cranial size of the breadth to length ratio($p<.001$); with cranial size group means the correlation of ratio group means is very weak (R =.384, p=.244; Appendix Table A.5.7 & Fig.5.4.11b).

SUMMARY: As a component of cranial size as defined, cranial length (GOL) is highly correlated with cranial size. Since frontal and parietal arcs are strongly correlated with cranial length they also show moderately high correlation with

Fig.5.4.9a Frontal Arc

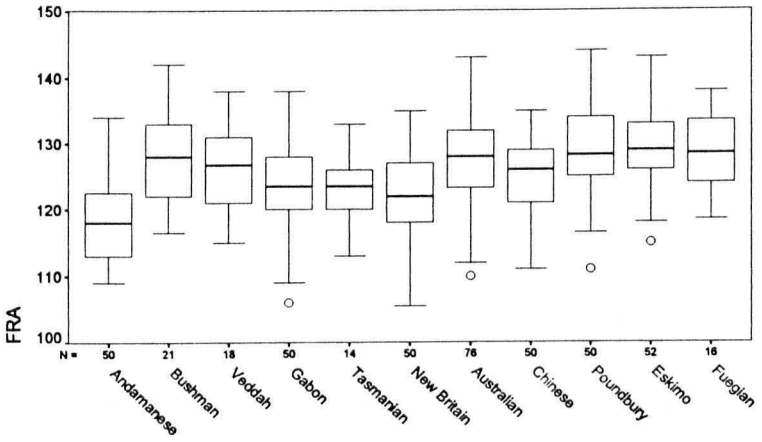
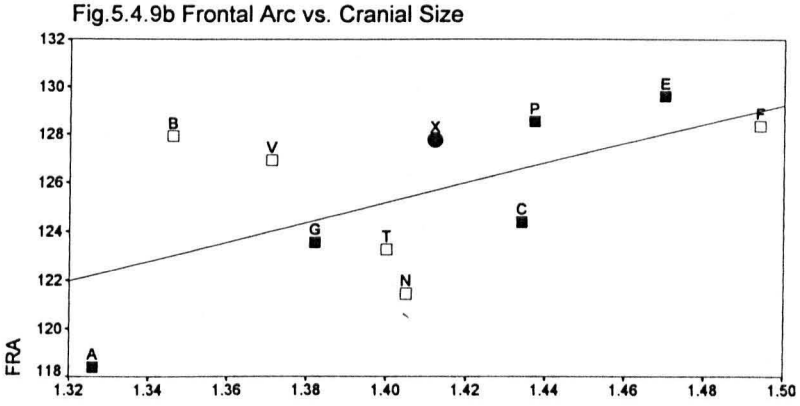


Fig.5.4.9b Frontal Arc vs. Cranial Size



Cranial Size (LBH)

FRA= 40.3 LBH + 68.8; R =.577, p =.063, n=11. (r =.642, p =.000, n=444)

Fig.5.4.10a Parietal Arc

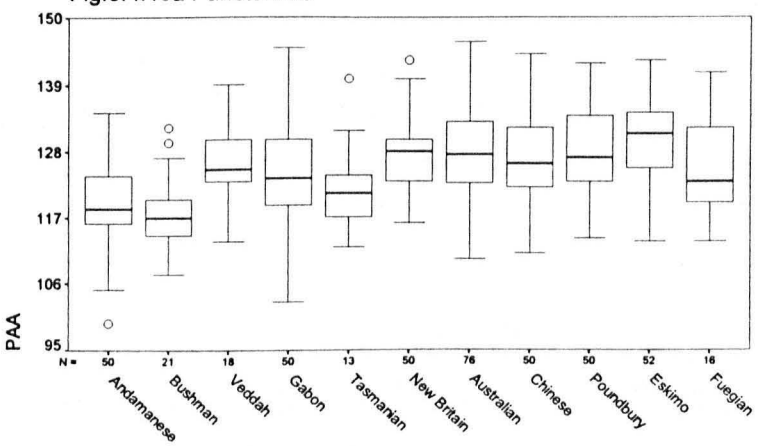
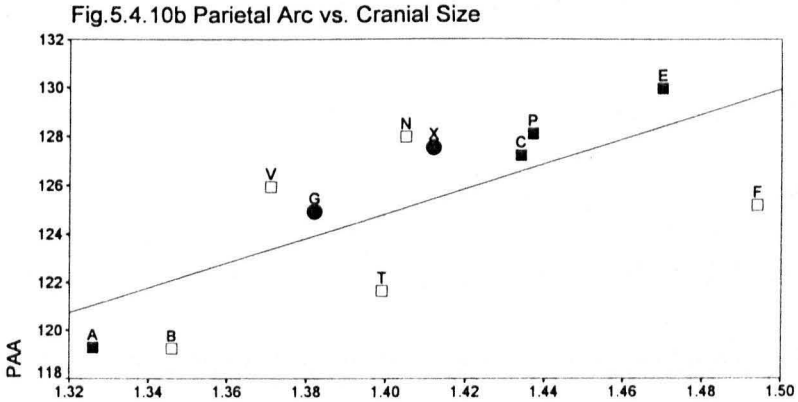


Fig.5.4.10b Parietal Arc vs. Cranial Size



Cranial Size(LBH)

PAA =50.9 LBH + 53.5; R =.707,p =.015, n =11. (r =.621,p =.000,n = 444)

Fig.5.4.11a Cranial Breadth(SCB)/Cranial Length(GOL) Ratio

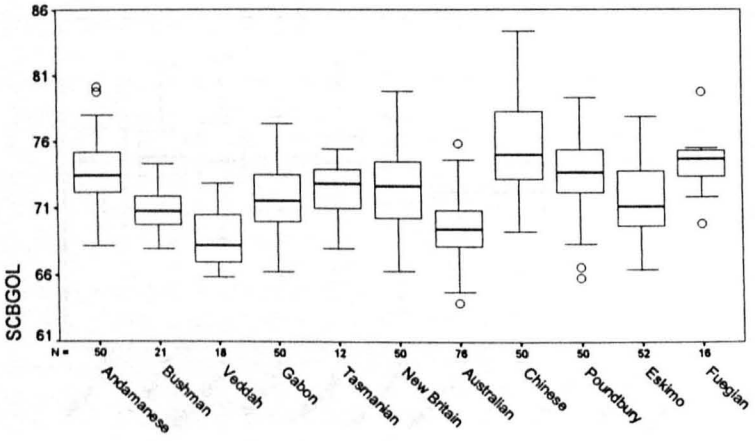
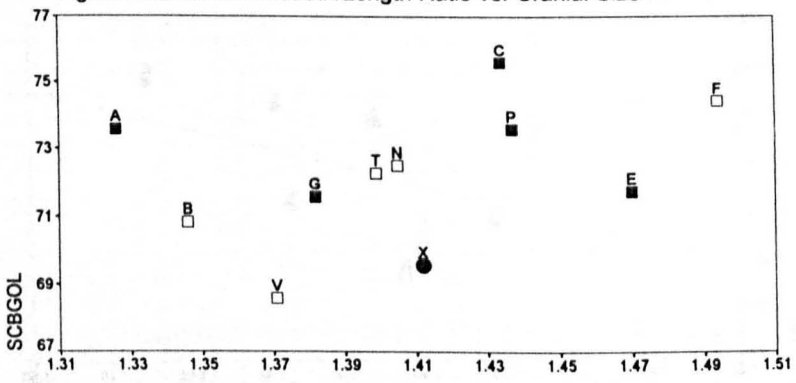


Fig.5.4.11b Cranial Breadth/Length Ratio vs. Cranial Size



R=.384, p=.244, n=11. (r =.065, p =.169, n=444)

Fig.5.4.12a Cranial Height (Basion-Bregma)

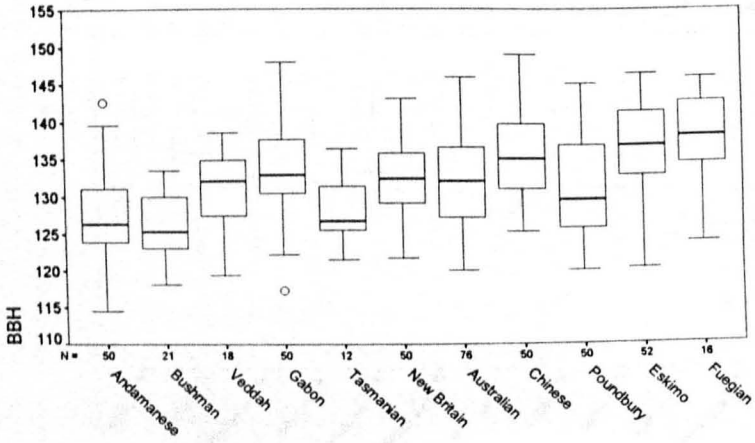
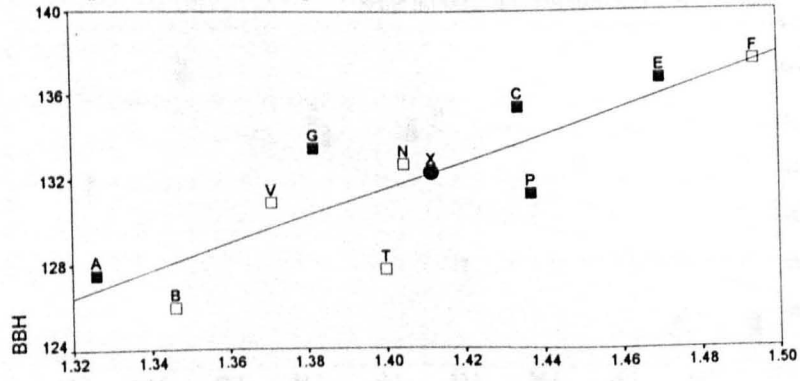


Fig.5.4.12b Cranial Height (Basion-Bregma) vs. Cranial Size



BBH=63.9 LBH + 42.1; R =.847, p =.001, n=11. (r =.807, p =.000, n=444)

cranial size. Cranial length to breadth ratio is independent of cranial size. Compared to other groups, Australian (with Poundbury) crania are absolutely and relatively long and have long frontal arcs. Australians (with Veddah and Eskimo) crania are narrow compared to length.

5.4.3.12 & 13 CRANIAL HEIGHT DIMENSIONS

5.4.3.12 BASION-BREGMA HEIGHT (BBH). Group absolute value distributions and means of Fuegian, Eskimo and Chinese crania are highest, those of Bushman, Andamanese and Tasmanian crania are lowest (Fig.5.4.12a and Appendix Table A.5.1). Bushman and Andamanese absolute means are significantly less than all but Tasmanian, Veddah and Poundbury means; Tasmanian and Poundbury means are significantly less than Eskimo and Fuegian means (p=.0000).

Correlation is strong for cranial height with cranial size (r =.807, p=.000), and for height group means with cranial size group means (R=.848, p=.001; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Tasmanian, Poundbury, and Bushman crania are low, Gabon and Chinese are high (Fig.5.4.12b).

5.4.3.13 STAPHYLION-HORMION HEIGHT (SPHO). Group absolute value distributions and means show that staphylion-hormion height is greatest for Fuegian and Chinese groups, least for Andamanese, Veddah and Gabon groups and intermediate for Australians (Fig.5.4.13a and Appendix Table A.5.1). The Fuegian absolute mean is significantly greater than those of all groups except Chinese, Poundbury and New Britain; the Chinese mean is also significantly greater than that of New Britain. Andamanese and Gabon means are significantly less than all others except Tasmanian, Bushman and Veddah means (p=.0000).

Correlation is moderate for staphylion-hormion height with cranial size (r =.561, p=.000), and for height group means with cranial size group means (R=.793, p=.004; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Eskimo, Gabon and Veddah have a small staphylion-hormion distance; for Chinese and Bushman the distance is relatively large (Fig.5.4.13b). Between- groups variation in this variable is not similar to the variation seen in cranial

height; high crania don't tend to have a large staphylion-hormion distance. There is significant correlation between the 2 variables but it is weak (r=.380, p<.001).

5.4.3.14-21 OCCIPITAL DIMENSIONS

5.4.3.14 OCCIPITAL ARC (OCA). Group absolute value distributions and means show close correspondence between occipital arc length and cranial size (Fig.5.4.14a and Appendix Table A.5.1). The Andamanese absolute mean is significantly less than those of the 6 groups with largest crania; Veddah and Gabon means are significantly smaller than those of the 4 groups with largest crania. The Australian absolute mean is intermediate, being significantly larger than the Andamanese mean, and significantly smaller than Fuegian, Eskimo and Poundbury means at p=.0000.

Correlation is moderate for occipital arc with cranial size (r =.668, p=.000), but very strong for arc group means with cranial size group means (R =.933, p=.000; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Bushman and Poundbury occipital arcs are large (Fig.5.4.14b).

5.4.3.15 OCCIPITAL CHORD/ARC RATIO (OCCOCA). A small ratio value indicates a high degree of occipital curvature, consistent with the presence of an occipital bun or a prominent occipital torus. Group absolute value distributions and means show that occipital chord/arc ratio is greatest for Gabon, intermediate for Australians, and least for Poundbury, Fuegian, Bushman and Tasmanian groups (Fig.5.4.15a and Appendix Table A.5.1). The Poundbury absolute mean is significantly less than all except Fuegian, Bushman and Tasmanian means; Gabon mean is significantly greater than all except the Andamanese mean, which in turn is significantly greater than all except Gabon and Veddah means (p=.0000).

Correlation is weak and negative for occipital chord/arc ratio with cranial size (r =-.332, p=.000), and moderate for the ratio group means with cranial size group means (R =-.529, p=.094; Appendix Table A.5.7). Compared to other groups and relative to cranial size, the Gabon occipital is particularly flat, those of Bushman, Poundbury and Tasmanian occipital are curved (Fig.5.4.15b).

Fig.5.4.13a Staphylion-Hormion Height

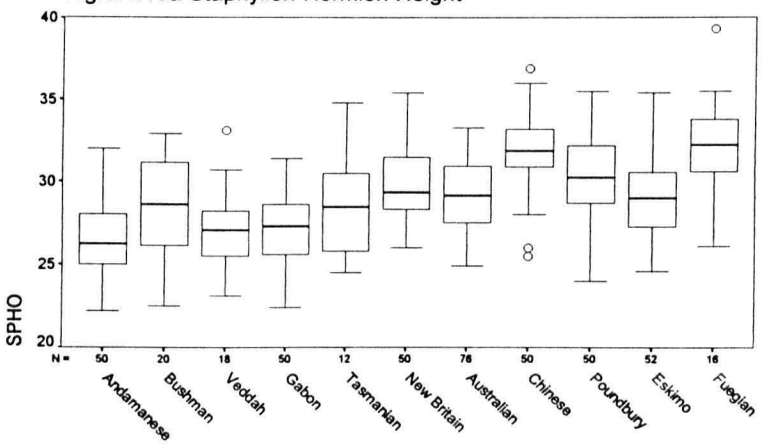
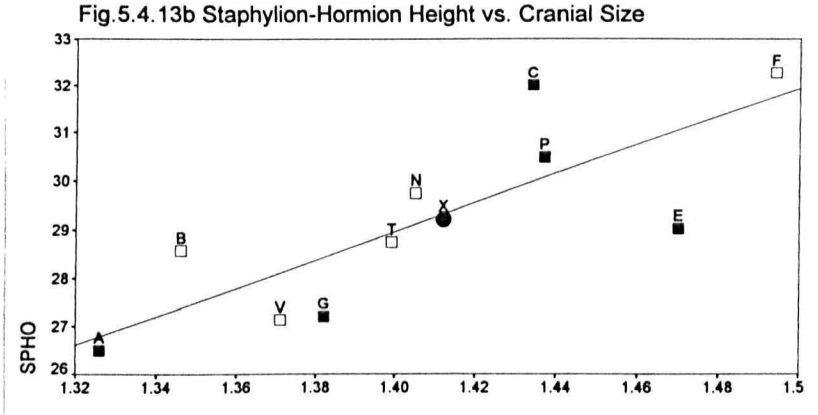


Fig.5.4.13b Staphylion-Hormion Height vs. Cranial Size



Cranial Size(LBH)

SPHO= 29.6 LBH - 12.4; R=.793, p =.004, n=11. (r =.561, p =.000, n=443)

Fig.5.4.14a Occipital Arc

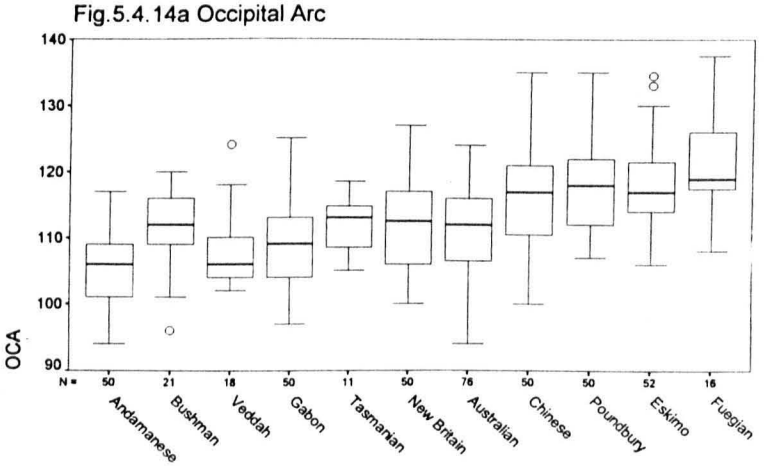
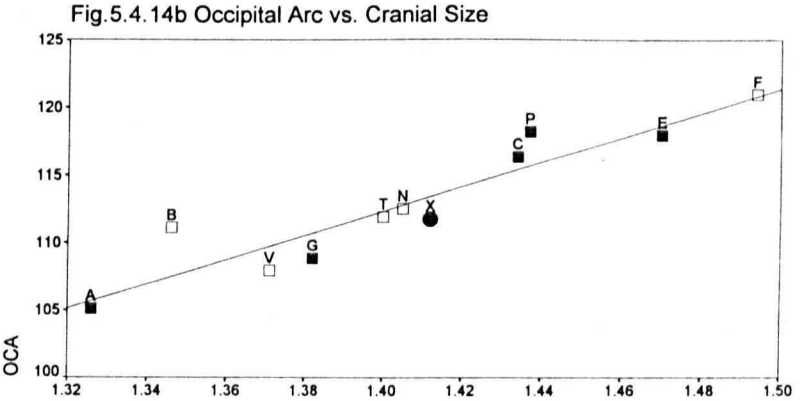


Fig.5.4.14b Occipital Arc vs. Cranial Size



Cranial Size (LBH)

OCA= 89.9 LBH - 13.5; R =.933, p =.000, n=11. (r =.668, p =.000, n=444)

Fig.5.4.15a Occipital Chord/Arc Ratio

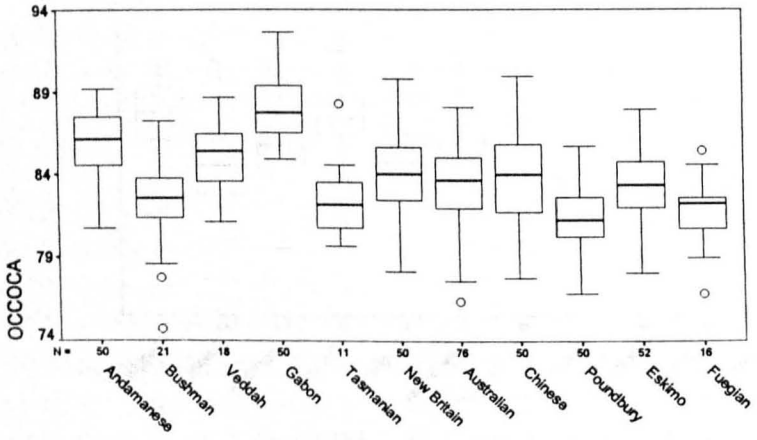
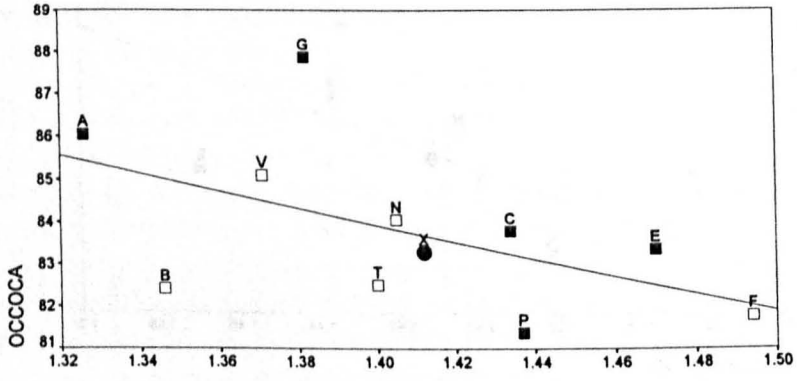


Fig.5.4.15b Occipital Chord/Arc Ratio vs. Cranial Size



OCCOCA= -20.3LBH + 112; R=-.529, p=.094, n=11. (r =-.332, p=.000, n=444)

Fig.5.4.16a Lambda-Inion Chord

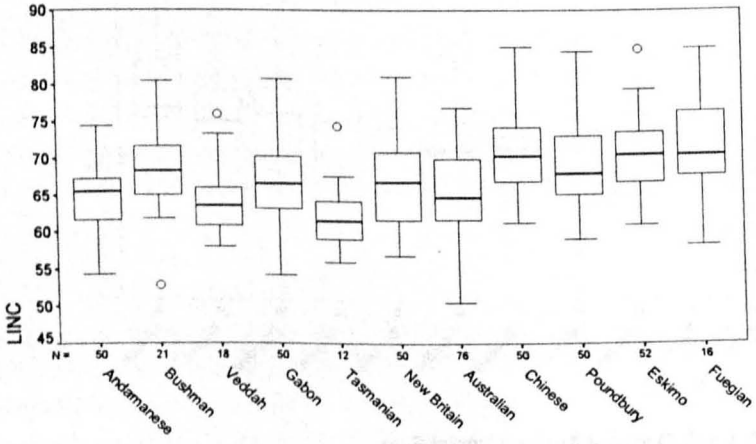
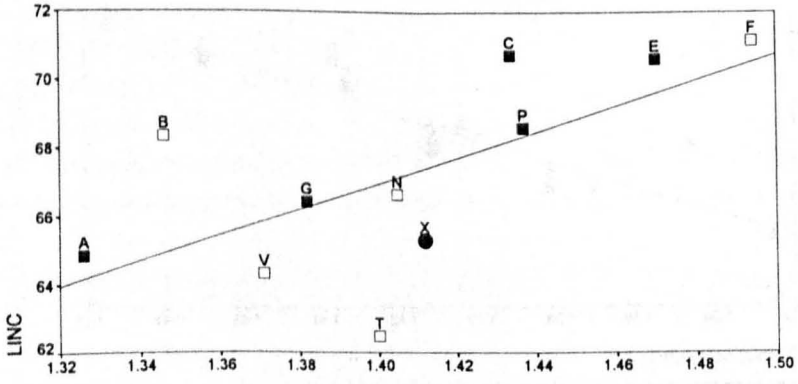


Fig.5.4.16b Lambda-Inion Chord vs. Cranial Size



LINC = 38.1 LBH + 13.7; R=.665, p=.026, n=11. (r =.438, p=.000, n=444)

5.4.3.16 LAMBDA-INION CHORD (LINC). Group absolute value distributions and means indicate that Eskimo, Chinese and Fuegian groups have the longest lambda-inion chord, Tasmanian the shortest (Fig.5.4.16a and Appendix Table A.5.1). Tasmanian, Andamanese and Australian absolute means are significantly less than Chinese and Eskimo means at p=.0000.

Correlation is weak for lambda-inion chord with cranial size (r =.438, p=.000), and moderate for chord group means with cranial size group means (R =.665, p=.026; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Chinese and Bushman lambda-inion chord is large, that of Veddah and Australian groups is small, and that of Tasmanians is very small (Fig.5.4.16b).

5.4.3.17 INION-OPISTHION CHORD (INOP). Group absolute value distributions and means indicate that Fuegian, Tasmanian and Poundbury groups have the longest inion-opisthion chord, Bushman and Andamanese the shortest (Fig.5.4.17a and Appendix Table A.5.1). The Bushman, Andamanese and Gabon absolute means are significantly less than Poundbury and Fuegian means; the Bushman mean is also significantly less than Chinese and Eskimo means; the Andamanese mean is also significantly less than Australian and New Britain means (p=.0000).

Correlation is weak for inion-opisthion chord with cranial size (r =.483, p=.000), but strong for chord group means with cranial size group means (R =.887, p=.000; Appendix Table A.5.7). Compared to other groups and relative to cranial size, the inion-opisthion chord of Tasmanians is very long, that of Bushman and Eskimo groups is short (Fig.5.4.17b).

5.4.3.18 LAMBDA-INION CHORD/INION-OPISTHION RATIO (LOIX). A small ratio results if the inion-opisthion chord is large relative to the lambda inion chord. Group absolute value distributions and means show that the ratio is greatest for the 2 groups with smallest crania, Bushman and Andamanese and Tasmanians have a particularly small ratio. Australian are intermediate (Fig.5.4.15a and Appendix Table A.5.1). There is only one significant difference between groups; the Tasmanian ratio mean is significantly smaller than the Bushman mean at p=.0000.

There is no correlation of lambda-inion/inion-opisthion

Fig.5.4.17a Inion-Opisthion Chord

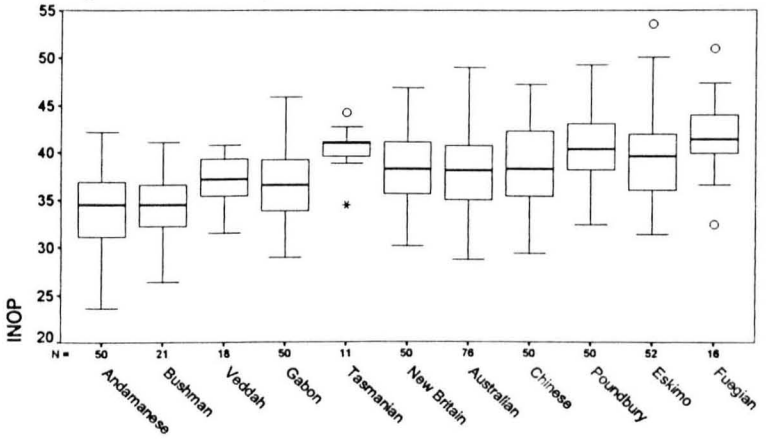
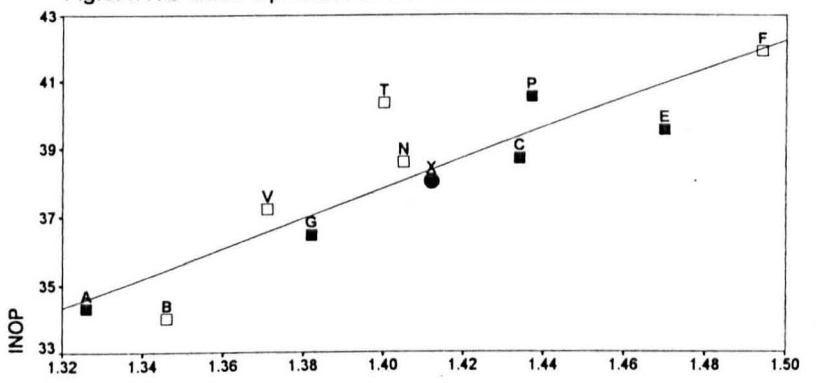


Fig.5.4.17b Inion-Opisthion Chord vs. Cranial Size



INOP= 43.9 LBH - 23.6; R =.887, p =.000, n=11. (r =.483, p=.000, n=444)

Fig.5.4.18a Lambda-Inion/Inion-Opisthion Ratio

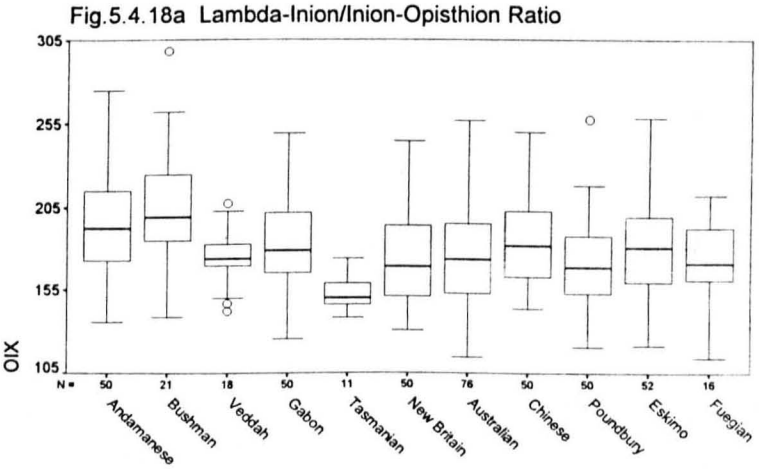
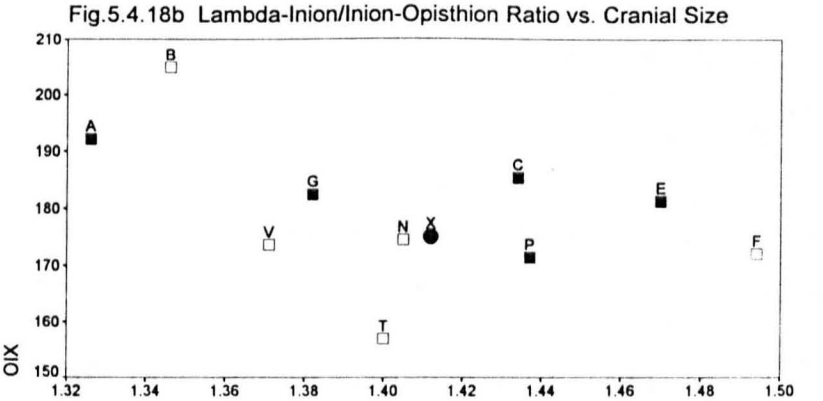


Fig.5.4.18b Lambda-Inion/Inion-Opisthion Ratio vs. Cranial Size



R = -.460, p = .155, n = 11. (r = -.130, p = .006, n = 444)

Fig.5.4.19a Endinion-Opisthion Chord

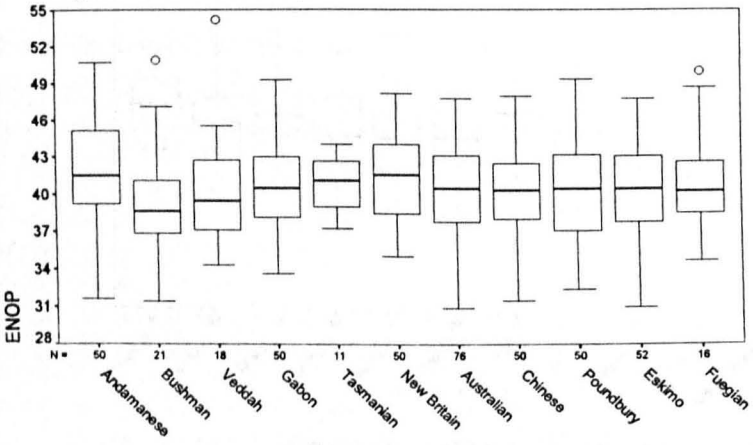
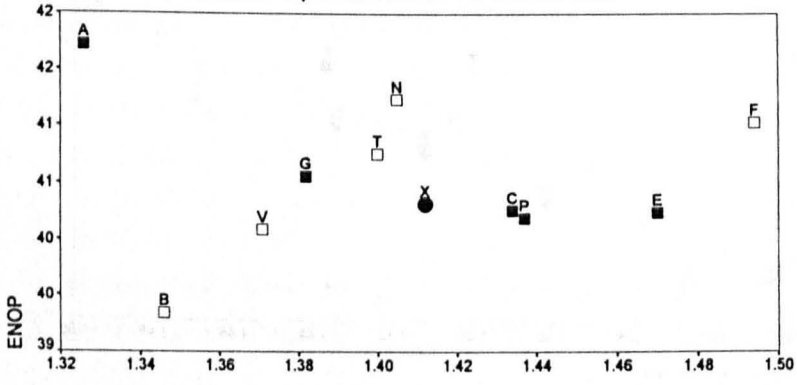


Fig.5.4.19b Endinion-Opisthion Chord vs. Cranial Size



R = -.023, p = .948, n = 11. (r = .086, p = .069, n = 444)

Fig.5.4.20a Endinion-Inion Separation

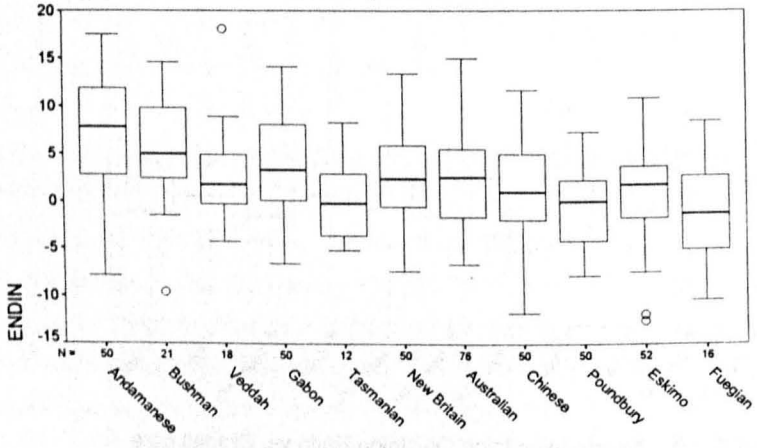
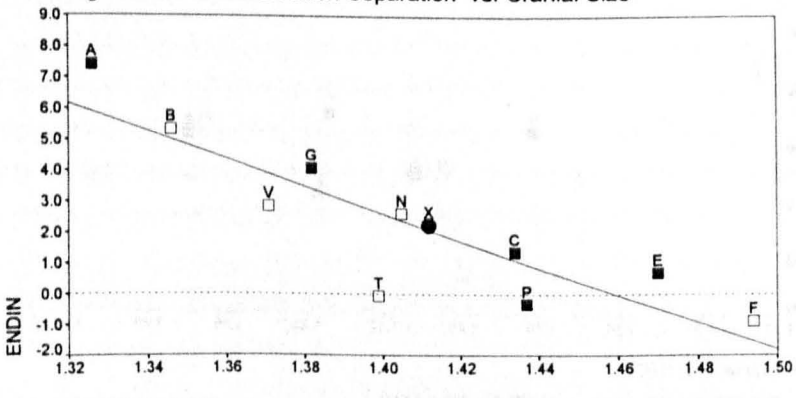


Fig.5.4.20b Endinion-Inion Separation vs. Cranial Size



ENDIN= -44.2 LBH + 64.5; R=-.876, p=.000,n=11. (r =-.346, p=.000,n =444)

ratio with cranial size, or of the occipital ratio group means with cranial size group means at p<.001 (Appendix Table A.5.7 & Fig.5.4.18b).

5.4.3.19 ENDINION-OPISTHION CHORD (ENOP) Group absolute value distributions indicate Andamanese have the longest endinion-opisthion chord and Bushman the shortest (Fig.5.4.19a). This is the only non-temporal variable considered for which there is no significant difference in means between groups at p=.0000. There is no correlation of endinion-opisthion chord with cranial size, nor of the chord group means with cranial size group means at p<.001 (Appendix Table A.5.7, Fig.5.4.19b).

5.4.3.20 ENDINION-INION CHORD SEPARATION (ENIN). Group absolute value distributions indicate Andamanese and Bushman have the largest endinion-inion separation, the near-zero means for Tasmanian and Poundbury groups correspond to a near coincident endinion and inion, and the negative Fuegian mean suggests a tendency in this group for inion to be above endinion (Fig.5.4.20a and Appendix Table A.5.1). The Andamanese absolute mean is significantly greater than all except Bushman, Gabon and Veddah means at p=.0000.

Correlation is negative and weak for endinion-inion separation with cranial size (r =-.346, p=.000), and negative and strong for endinion-inion separation group means with cranial size group means (R=-.876, p=.000; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Andamanese crania have endinion placed high relative to inion, Tasmanian and Poundbury crania have endinion placed low relative to inion (Fig.5.4.20b).

5.4.3.21 OPISTHOCRANION-INION ARC SEPARATION (OCNINA). Group absolute value distributons and means show that Gabon opisthocranion-inion separation is particularly large, and Tasmanian, New Britain, Eskimo and Fuegian groups have the smallest separation. The Australian separation is intermediate (Fig.5.4.21a and Appendix Table A.5.1). The Gabon absolute mean is significantly greater than those of all groups except Veddah and Bushman at p=.0000.

There is no correlation of opisthocranion-inion

Fig.5.4.21a Opisthocranion-Inion Arc

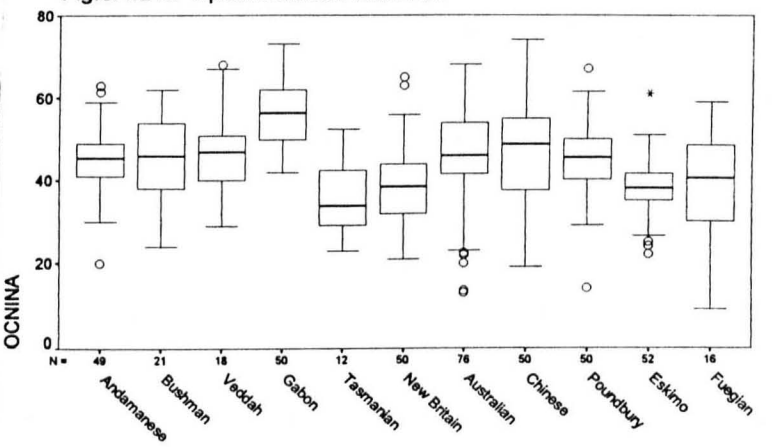
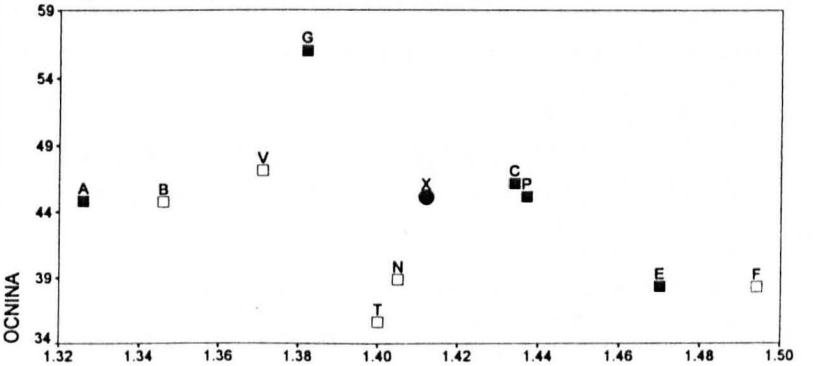


Fig.5.4.21b Opisthocranion-Inion Arc vs. Cranial Size



Cranial Size (LBH)

R = -.419, p = .200, n = 11. (r = -.016, p = .743, n = 443)

Fig.5.4.22a Foramen Magnum Length

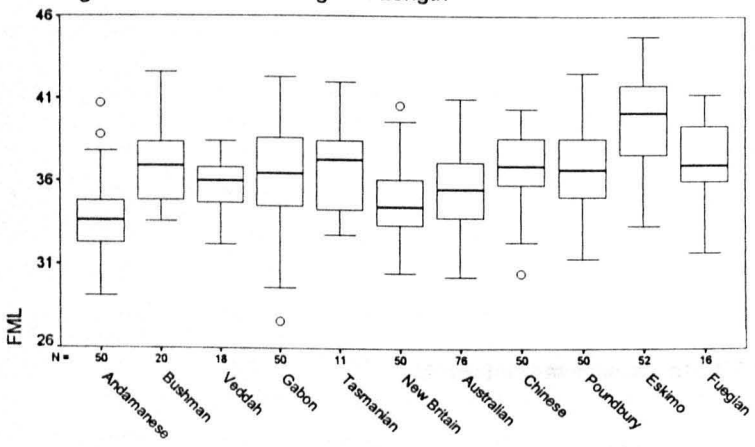
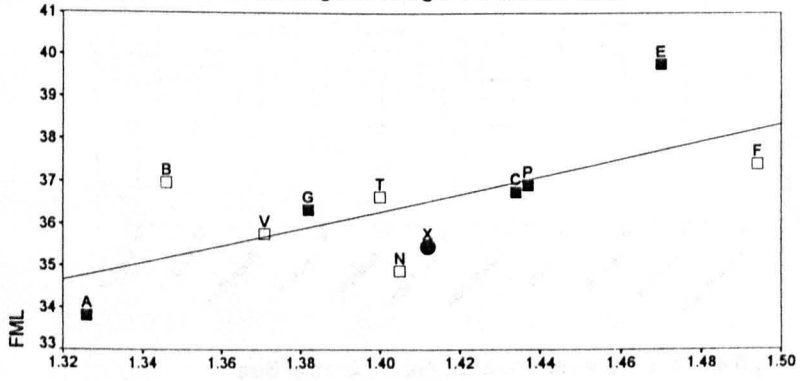


Fig.5.4.22b Foramen Magnum Length vs. Cranial Size



Cranial Size (LBH)

FML=20.3 LBH + 7.83; R =.671, p =.024, n=11. (r =.588, p =.000, n=443)

Fig.5.4.23a Foramen Magnum Width

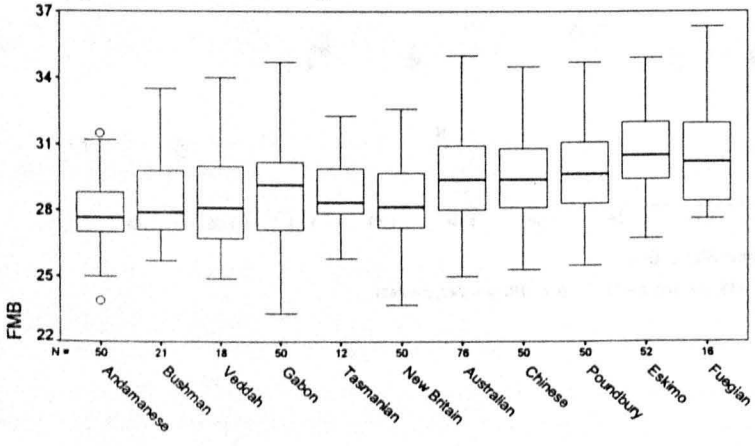
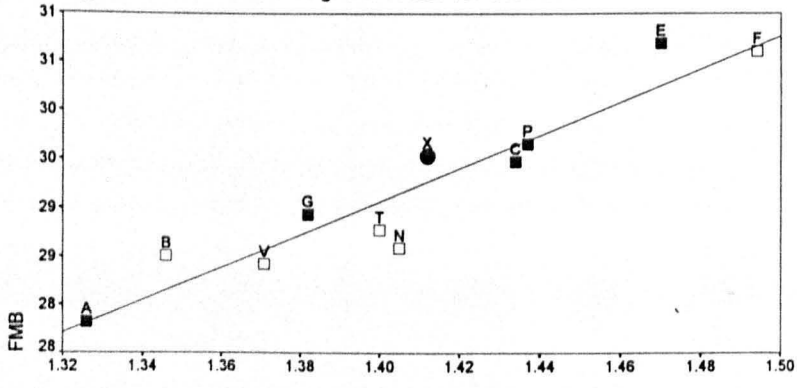


Fig.5.4.23b Foramen Magnum Width vs. Cranial Size



Cranial Size (LBH)

FMB=17.0 LBH + 5.30; R =.946, p =.000, n=11. (r =.521, p =.000, n=444)

separation cranial size, or of the separation group means with cranial size group means ($p < .001$; Appendix Table A.5.7 & Fig.5.4.21b). The small opisthocranion-inion separation of Tasmanian, Eskimo, Fuegian and New Britain crania may be associated with the prevalence of prominent occipital tori in those groups. Similarly, the particularly large opisthocranion-inion separation of Gabon crania may be associated with the fact that Gabon crania have the least curved occipital.

SUMMARY: Of the 8 occipital variables considered, only occipital arc shows substantial correlation with cranial size; the others have weak to negligible correlation. Relatively and absolutely, Australians have a comparatively small lambda-inion chord but are intermediate in all other occipital variables. The occipital of Gabon crania is very flat with a large opisthocranion-inion separation, while that of Bushmen, Poundbury and Tasmanians is particularly curved. According to group means, the 2 groups with smallest crania have endinion positioned high above inion, Fuegians with the largest crania tend to have inion higher than endinion, and inion and endinion are coincident on Poundbury and Tasmanian crania.

5.4.3.22,23 FORAMEN MAGNUM DIMENSIONS

5.4.3.22 FORAMEN MAGNUM LENGTH (LFML). Group absolute value distributons and means show that the foramen magnum of Eskimos is particularly long, that of Andamanese particularly short (Fig.5.4.22a and Appendix Table A.5.1). The Eskimo absolute mean is significantly greater than those of all groups except Fuegian, the Andamanese mean is significantly less than all others except New Britain, Australian and Veddah means at $p=.0000$.

Correlation is moderate for foramen magnum length with cranial size ($r=.588$, $p=.000$) and for height group means with cranial size group means ($R=.671$, $p=.024$; Appendix Table A.5.7). Compared to other groups and relative to cranial size, the foramen magnum of Eskimo and Bushman groups is long, that of New Britain, Australian, Andamanese and Fuegian groups is short (Fig.5.4.22b). Between-groups variation in this variable is not similar to the variation seen in cranial length though there is moderate correlation between the 2 variables ($r=.567$, $p<.001$).

5.4.3.23 FORAMEN MAGNUM WIDTH (LFMB). According to group absolute value distributons and means, the widest foramen magnum belong to groups with largest crania, the narrowest foramen magnum to groups with the smallest crania (Fig.5.4.23a and Appendix Table A.5.1). The Andamanese absolute mean is significantly less than Eskimo, Fuegian, Poundbury and Australian means; the Eskimo mean is also sigtnificantly greater than that of New Britain (p=.0000).

Correlation is moderate for foramen magnum width with cranial size (r =.521, p=.000), but very strong for foramen magnum width group means with cranial size group means (R=.946, p=.000; Appendix Table A.5.7). Compared to other groups and relative to cranial size, the foramen magnum of Eskimo, Bushman, Australian and Gabon groups is slightly wide, that of New Britain narrow (Fig.5.4.23b).

5.4.3.24-26 NASAL APERTURE

5.4.3.24 AVERAGE NASAL HEIGHT (NLH). Group absolute value distributons and means show that nasal aperture height is particularly small for Bushman, and largest for the 4 groups with largest crania, Eskimos, Fuegians, Poundbury and Chinese; Australian nasal height is intermediate (Fig.5.4.24a and Appendix Table A.5.1). The Fuegian, Poundbury, and Chinese absolute means are significantly greater than all others except those of Eskimos and Australians; the Eskimo mean is also significantly greater than the Australian mean, which in turn is significantly greater than Bushman, Tasmanian, and Andamanese means; the Bushman mean is significantly smaller than all except Tasmanian, Andamanese and Veddah means (p=.0000).

Correlation is quite strong for nasal aperture height with cranial size (r =.723, p=.000), and strong for nasal height group means with cranial size group means (R=.891, p=.000; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Tasmanian and Bushman means are particularly small (Fig.5.4.24b).

5.4.3.25 NASAL APERTURE WIDTH (NLB). Group absolute value distributons and means indicate that Australian, Tasmanian, Gabon and New Britain groups have the widest nasal apertures, and Eskimos have the narrowest (Fig.5.4.25a, Appendix Table

Fig.5.4.24a Nasal Aperture Height (av.)

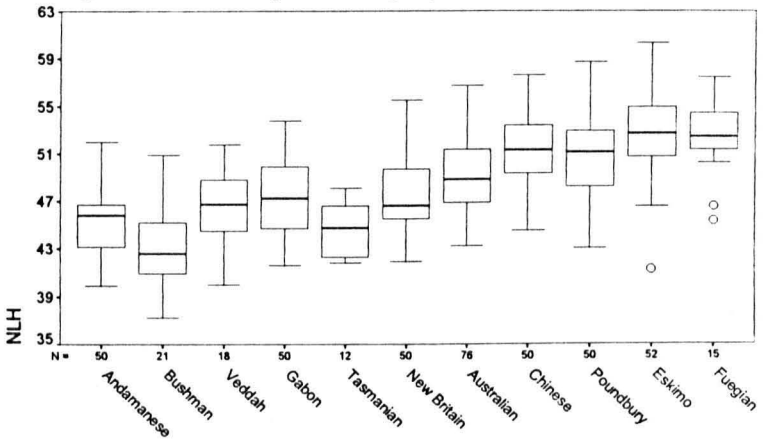
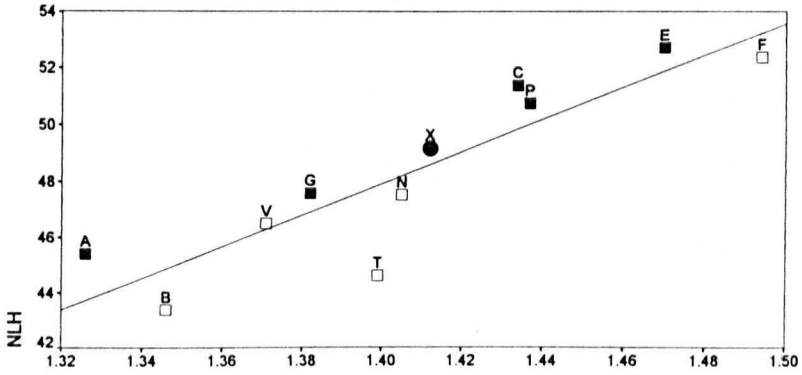


Fig.5.4.24b Nasal Aperture Height vs. Cranial Size



Cranial Size (LBH)

NLH = 56.5 LBH - 31.2; R =.891, p =.000, n=11. (r =.723, p =.000, n=443)

Fig.5.4.25a Nasal Aperture Width

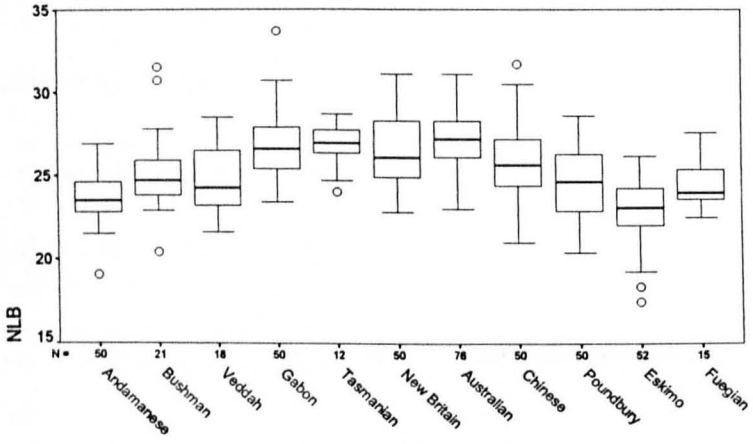
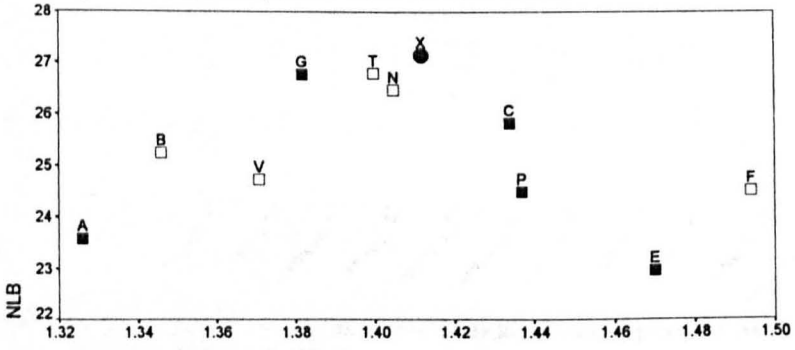


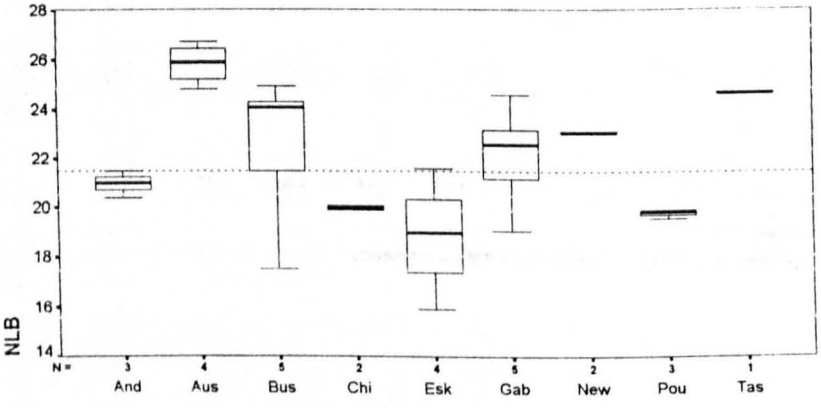
Fig.5.4.25b Nasal Aperture Width vs. Cranial Size



NLB = -4.22LBH + 31.3; R =-.152, p=.655, n=11. (r =.193, p =.000, n=443)

Nasal aperture is wide for AustraloMelanesian & Gabon, narrow for Eskimo

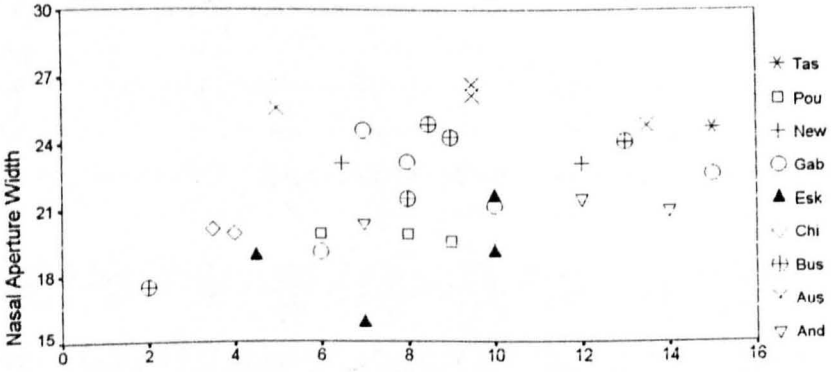
Fig.5.4.25c Nasal Aperture Width in Juveniles, 2-15yrs.



Juvenile nasal aperture is widest in Australians, narrowest in Eskimos.

It is also wide in Tasmanians, narrow in Poundbury & Chinese.

Fig.5.4.25d Nasal Aperture Width Vs. Age (Juveniles)



Already narrow in Eskimos,wide in Australomelanesians, nasal aperture in juveniles does not noticeably increase with age, at least after 4 years.

A.5.1 and Plate 5.2). The Australian absolute mean is significantly greater than Eskimo, Andamanese, Poundbury, Fuegian and Veddah means; New Britain and Gabon means are significantly greater than Eskimo, Andamanese and Poundbury means; the Eskimo mean is significantly less than Bushman, Chinese, New Britain, Gabon, Tasmanian and Australian means (p=.0000). These results coincide with those of Franciscus & Long (1991:422,423) who found that Australians then Africans have the widest nasal apertures, Eskimos the narrowest.

Contrary to the situation for nasal aperture height, correlation of nasal aperture width with cranial size is extremely weak (r=.193, p=.000), and negligible for nasal width group means with cranial size group means at p<.001 (Appendix Table A.5.7 & Fig.5.4.25b).

This pattern of between-groups variation in nasal aperture width is already evident in juvenile crania as can be seen in Figs.5.4.25.c & d. There is no indication of increase in nasal width with age after 4 years at least, and the Australian aperture is already as extremely wide as Eskimo aperture is narrow.

5.4.3.26 NASAL WIDTH/HEIGHT RATIO (NBHX). Group absolute value distributons and means show that nasal width/height ratio is greatest for Tasmanian and Bushman groups, and smallest for Eskimos, Fuegians and Poundbury (Fig.5.4.26a and Appendix Table A.5.1). Australian, New Britain, Gabon and Bushman absolute means are significantly greater than all others except that of Veddah; the Tasmanian mean is also significantly greater than that of Veddah; the Eskimo mean is significantly less than all other means except that of Fuegian; Fuegian and Poundbury means are significantly less than all other means except Eskimo and Chinese (p=.0000).

Correlation is negative and weak for nasal width/height ratio with cranial size (r =-.365, p=.000), and negative and moderate for nasal ratio group means with cranial size group means (R=-.676, p=.022; Appendix Table A.5.7). Compared to other groups and relative to cranial size, Tasmanian, Australian, New Britain, Gabon and Bushman nasal width/height means are large, Andamanese and Eskimos means are particularly small (Fig.5.4.26b).

5.4.3.27 NASAL APERTURE AREA (NLA). Group absolute value distributons and means show that nasal area is greatest for

Australian, and Chinese groups, and smallest for Andamanese and Bushman (Fig.5.4.27a and Appendix Table A.5.1). Australian and Chinese absolute means are significantly greater than those of Andamanese, Bushman and Veddah; Bushman absolute means is also significantly smaller than that of Gabon, Andamanese absolute means is significantly smaller than all except Bushman, Veddah and Tasmanian means (p=.0000).

Correlation is positive and moderate for nasal area with cranial size (r =.585, p=.000), and positive and quite strong for nasal area group means with cranial size group means (R=.727, p=.012; Appendix Table A.5.7). Compared to other groups and relative to cranial size, the Australian nasal area mean is the largest, the Eskimo mean is the smallest. Gabon, Chinese and to less extent, New Britain means are also relatively large, and Fuegians, Bushman and Andamanese means are relatively small (Fig.5.4.27b).

SUMMARY: Of the 4 nasal aperture dimensions considered, the width offers the best means of population discrimination. The correlation with cranial size is strong and positive for nasal height, moderate for area, weak and negative for width/height ratio and extremely weak for width. Nasal width is a particularly distinguishing feature for Australian and Eskimo crania. Australo-Melanesian and African groups have particularly wide nasal aperture. Gabon, New Britain and especially Australian crania have a large nasal area, absolutely and relatively. Eskimos have a particularly narrow nasal aperture, small nasal area and low width/height ratio.

The remarkably narrow nasal aperture and small nasal index of Eskimos has long been recognised (Duckworth 1900:135; Furst & Hansen 1915:50,157; Morant 1937:18; Oetteking 1931:444) and was thought to be aquired in the course of growth. This may be true of nasal index since nasal height has strong positive association with cranial size. But it is not so for nasal aperture width since it is virtually independent of cranial size and the narrowness of Eskimo nasal aperture compared to that of other groups is already evident in the juvenile (Plate 5.2, Figs 5.4.25c & d).

A narrow, high nose is regarded as an adaptation to a cold, dry environment by more efficiently warming and moistening inspired air and recovering heat and moisture from expired air, while a low, wide nose more effectively

Fig.5.4.26a Nasal Width/Height Ratio

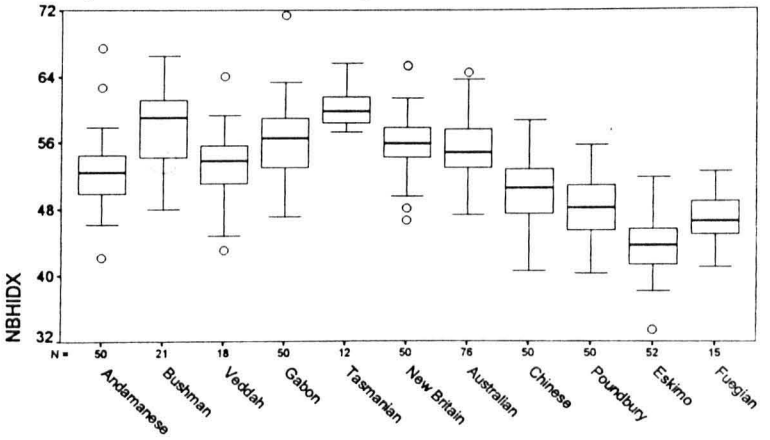
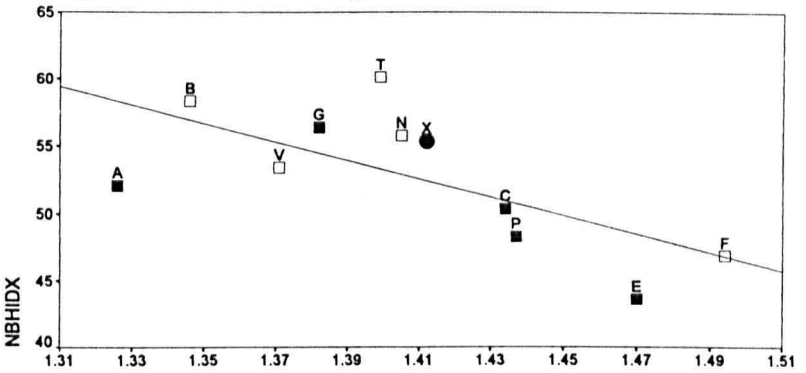


Fig.5.426b Nasal Width/Height Ratio vs. Cranial Size



Cranial Size(LBH)

NBHIDX= -68.2 LBH + 149; R=-.676, p=.022, n=11. (r=-.363, p=.000, n=443)

Fig.5.4.27a Nasal Aperture Area

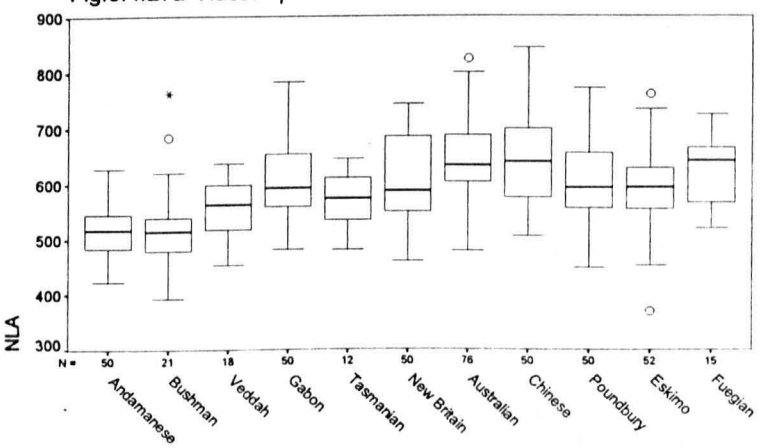
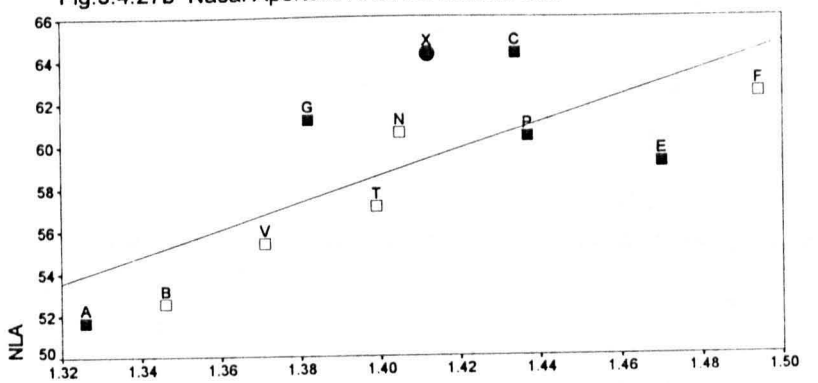


Fig.5.4.27b Nasal Aperture Area vs. Cranial Size



Cranial Size(LBH)

NLA = 62.5 LBH - 28.9; R =.727, p =.011, n=11. (r =.585, p =.000, n=443)

Fig.5.4.28a (Staphylion-Hormion-Basion) Base Angle

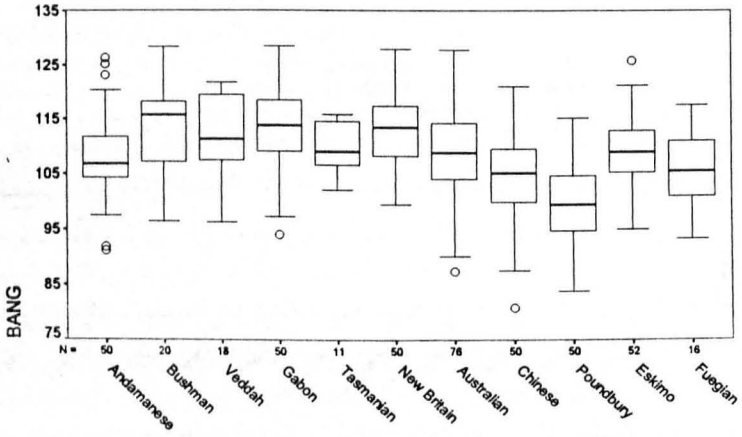
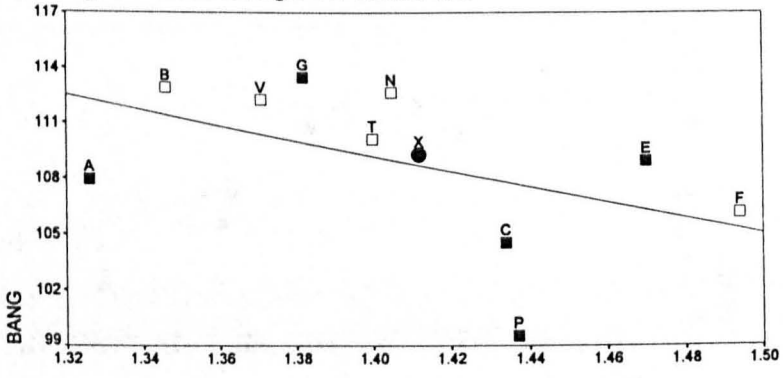


Fig.5.4.28b Base Angle vs. Cranial Size



BANG=-41.6 LBH + 167; R =-.496, p=.121, n=11. (r =-.290, p=.000, n=442)

Fig.5.4.29a (Staphylion-Hormion-Opisthion) Foramen Magnum Angle

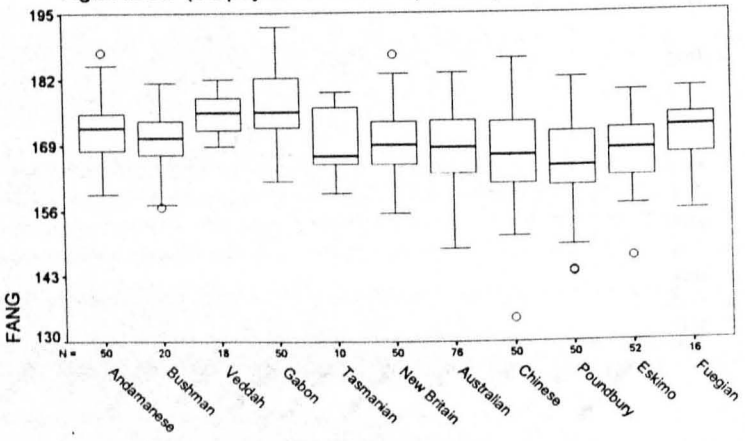
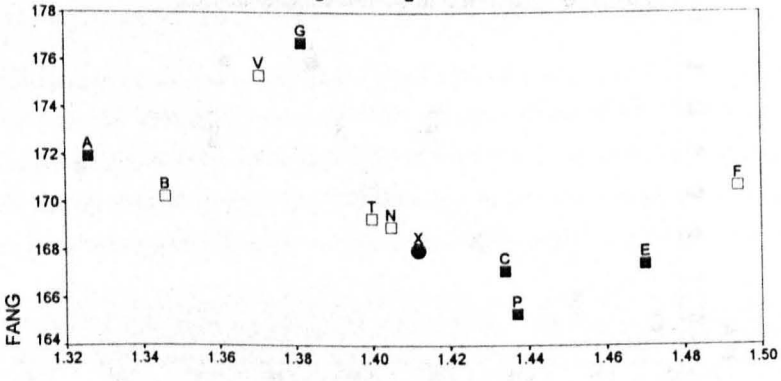


Fig.5.4.29b Foramen Magnum Angle vs. Cranial Size



FANG=-33.6 LBH + 217; R =-.490, p=.126, n=11. (r =-.090, p=.058, n=442)

dissipates heat in hot humid climates (Franciscus & Long 1991:425; Carey & Steegman 1981:317). Wolpoff showed that it is nasal aperture width rather than height which reponds to climatic selection; he found that nasal breadth decreses within a population of (i) Eskimos and (ii) Australians as the climate becomes cooler and drier (Wolpoff 1981:410-413,418). The finding in this study of the dependence of nasal height on cranial size and nasal width's independence of cranial size is consistent with Wolpoff's conclusion. However, Carey and Steegman pointed out the importance of also considering the volume of the nose by taking into account the degree of protrusion as well as width and height, and found the lower the absolute humidity and (less critically) the colder the climate the more the nose projects (Carey & Steagman 1981:313,315). Glanville (1969:29) considered that nasal shape is related to prognathism and maxillary dental arch shape, such that prognathism tends to be accompanied by an increasingly broad and short nose. Certainly Australian, New Britain and Gabon crania do not only have comparatively wide nasal apertures but are also regarded as being prognathic, but as a quantitative measure of prognathism has not been included in this study a general link between prognathism and wide nasal aperture cannot be investigated ~~in~~ here.

5.4.3.28,29 BASE ANGULATION

5.4.3.28 (STAPHYLION-HORMION-BASION) BASE ANGLE (BANG). Group absolute value distributions and means show that the base angle is least for Poundbury and greatest for Gabon, Bushman, New Britain and Veddah; the Australian mean is intermediate (Fig.5.4.28a and Appendix Table A.5.1). The Poundbury absolute mean is significantly less than all except Fuegian and Chinese means; the Chinese mean is significantly less than Gabon and New Britain means (p=.0000).

Correlation is negative and weak for the base angle with cranial size (r =-.290, p=.000), and negligible for base angle group means with cranial size group means (p<.1; Appendix Table A.5.7). Compared to other groups and relative to cranial size, the Poundbury mean is particularly small; Chinese and Andamanese means are also small (Fig.5.4.28b).

In a study involving African, Australian, Chinese and Poundbury cranial samples, Luboga and Wood also found that

Poundbury crania are the most flexed and that African and Australian cranial are flatter than Chinese and Poundbury (Luboga 1986:248,271,348 Luboga & Wood 1990:72). George (1978:171) found that the modern human cranial base becomes more flexed during the first 2 years after birth, remaining stable thereafter. It is also by the end of 2 years that the rapid expansion of the cerebellum in modern humans is completed (Dean 1988:109).

5.4.3.29 FORAMEN MAGNUM ANGLE (STAPHYLION-BASION-OPISTHION) (FANG). Group absolute value distributions and means show that the foramen magnum angle is greatest for Gabon and Veddah, least for Poundbury and intermediate for Australian groups (Fig.5.4.29a and Appendix Table A.5.1). The Poundbury absolute mean is significantly less than Gabon, Veddah and Andamanese means; the Gabon mean is significantly greater than Poundbury, Eskimo, Chinese, Australian and New Britain means ($p=.0000$). These results confirm those of Luboga and Wood in studies involving Poundbury, African, Australian and Chinese cranial samples (Luboga & Wood 1990:71, Luboga 1986:352)

There is no correlation of foramen magnum angle with cranial size, or of f.m. angle group means with cranial size group means at $p<.001$ (Appendix Table A.5.7 & Fig.5.4.29b). Nor was correlation found between the foramen magnum angle and cranial base angle at $p<.01$ (Appendix Table A.5.2). Luboga also found foramen magnum angle to be unrelated to cranial base angle (Luboga & Wood 1990:67).

SUMMARY: Correlation with cranial size is weak and negative for cranial base flexion and negligible for foramen magnum orientation. In both variables, Australian crania have intermediate values only. Bushmen, Gabon, Veddah and New Britain crania have the flattest bases, Gabon and Veddah the least forward rotated foramen magnum. Poundbury crania are the most flexed, relatively and absolutely, and have the most forward rotated foramen magnum. Andamanese and Chinese crania are also comparatively flexed.

In Section 5.3.3.26, reference was made to the study by Schulter with regard to petrous sagittal and petrous-tympanic angles. Base flexion was also measured in that study, and the Eskimo cranial base was found to be flatter than Amerindian or Caucasian, and Caucasian the most flexed (Schulter

1976:461,466,467). The results of this analysis concur with Schulter's findings that Poundbury crania have the most flexed crania of all 11 modern human groups examined, and the Eskimo cranial base is flatter than that of Chinese, though by no means the flattest of all groups represented. Schulter found cranial base flexion, as well as petrous and petrous-tympanic orientation, to be independent of overall cranial dimensions at $p = .001$, and regarded this as an indication that the base is not influenced during growth by the developing brain, and may rather restrict inferior expansion of the brain, augmenting expansion in other directions (Shulter 1976:466). The correlation coefficients obtained in this study (Appendix Table A.5.2) suggest that the association of overall cranial dimensions with cranial base flexion, with petrous orientation and with the petrous-tympanic angle is weak but nevertheless complete independence of brain expansion is not indicated. (See also Section 8.2.3.6).

5.4.4 SUMMARY OF BETWEEN-GROUPS VARIATION FOR 29 NON-TEMPORAL VARIABLES

5.4.4.1 CORRELATION OF 29 NON-TEMPORAL VARIABLES WITH CRANIAL SIZE (Appendix Table A.5.7).

(i) All but 3 of the 22 linear non-temporal variables have significant positive correlation with cranial size at $p<.001$; the correlation strength varied from strong to very weak ($r = .874$ to $r = .193$, $p = .000$), 8 of the variables being more strongly correlated with cranial size than any temporal variable.

(ii) One linear, one angular and two ratio non-temporal variables (endinion-inion separation, base angle, nasal width/height ratio and occipital chord/arc ratio) have significant but weak negative correlation with cranial size ($r = -.363$ to $r = -.290$, $p = .000$).

(iii) There is no significant correlation with cranial size at $p<.001$ for the remaining 5 non-temporal variables, endinion-opisthion chord, opisthocranion-inion arc, foramen magnum angle, lambda-inion/inion-opisthion ratio and cranial breadth/length ratio.

5.4.4.2 SIGNIFICANT DIFFERENCES IN ABSOLUTE GROUP MEANS OF NON-TEMPORAL VARIABLES.

(iv) Significant difference between group means exists for all non-temporal variables except endinion-opisthion chord at $p<.001$.

(v) As is the case for temporal variables, groups with larger crania tend to have significantly larger mean values for linear non-temporal variables than other groups. The same trend is not apparent if the non-temporal (or temporal) variables concerned are angular or ratios (Appendix Tables A.5.8.1 & 2). This finding is consistent with most linear variables having some dependence on cranial size, and most non-linear variables being independent of cranial size.

(vi) Of the 11 population groups (Appendix Table A.5.8.3): * Andamanese significantly differ in linear non-temporal measurements most often. Since the same was true for temporal variables, this suggests that in size-related

variables, Andamanese crania significantly differ most.

* In non-linear non-temporal variable means, Andamanese and Eskimos significantly differ more often than other groups, but only marginally so.

(vii) Of the 6 regionally distinct population groups:

* Australian and Gabon have fewest significant differences in linear non-temporal means, possibly reflecting the intermediate magnitude of their linear cranial dimensions and the association of most linear variables with cranial size.

* Australians have fewest significantly different non-linear non-temporal means. The contrast with the finding that Australians and Eskimos have the greatest number of significant differences if the non-linear variables are temporal, suggests that Australians differ significantly from the other 5 main groups more in temporal than in non-temporal variables.

(viii) The only non-temporal variable for which a group's absolute mean value differs significantly from the means of the other 10 groups is glabella-opisthocranion cranial length. Andamanese cranium is significantly shorter than all others.

(ix) Of the 6 regionally distinct population groups, the non-temporal variables for which a group's absolute mean value differs significantly from the means of the other 5 groups are:

(1) The Eskimo nasal width/height ratio is smaller.
(2) The Eskimo foramen magnum is longer.
(3) The Poundbury occipital chord/arc ratio is smaller.
(4) The Gabon opisthocranion-inion arc is longer.
(5) The Andamanese biasterion breadth is smaller.
(6) The Andamanese bisupramastoid crest breadth/maximum parietal breadth ratio is smaller.
(7) The Andamanese nasal area is smaller.

(x) No Australian non-temporal variable mean differs significantly from that of all other 10 groups or from all other 5 large sample, regionally distinct groups.

5.4.4.3 AUSTRALIAN NON-TEMPORAL CHARACTERISTICS

(xi) Based on absolute values and on means relative to cranial size group means, Australian crania are characterised by the following non-temporal features:

(1) a cranium which is intermediate in overall size, absolutely and relatively long, intermediate in height and narrow across the parietals. In all other overall cranial breadth dimensions the absolute means are intermediate; however, relative to cranial size, biauricular breadth, bisupramastoid crest breadth, and minimum cranial breadth are small, bizygomatic breadth is quite large and biasterion breadth is intermediate.

(2) a cranium which is narrow for its length and broad towards the base compared to across the parietals. (The cranial breadth/length ratio is small, the supramastoid crest breadth/ max. parietal breadth ratio is large, absolutely and relatively.)

(3) nasal aperture which is absolutely and relatively wide, intermediate in height, large in area and relatively wide for its height.

(4) relatively long frontal and parietal arcs.

(5) relatively short foramen magnum.

(6) an occipital which is intermediate absolutely and relatively in all dimensions except lambda-inion chord which is absolutely and relatively short.

(7) intermediate staphylion-hormion height.

(8) intermediate foramen magnum and base angles.

Chapter 6
TEMPORAL VARIABLE RELATIONSHIPS: FACTOR ANALYSIS

6.1 INTRODUCTION

6.1.1 PURPOSE

Factor analysis was applied to the data to reveal what underlying relationships exist between the variables. It was also used to determine which variables or combinations of variables distinguish Australians from other modern groups. Answers were sought to the following questions:

1. How are the temporal variables related to:
   a. each other?
   b. overall cranial size?
   c. base angulations?
   d. shape-related variables?
   e. some specific non-temporal variables?

2. Can Australian crania be distinguished from other population samples on the basis of the temporal variables used in this study? If so, which variables or group of variables characterize the Australians?

6.1.2 PROCEDURE

After consideration of correlation coefficients and results of trial factor analyses, several variables were excluded from the analysis for one or more of the following reasons: Excessively high correlations ($r > .80$), lack of sufficient significant correlation (no $r > .30$, $p < .001$), repeatedly low values for communalities($< .50$), factor loadings ($< .40$) or sampling adequacy (MSA $< .50$). (Hedderson 1991:172; Norusis 1993b:50-53; Tabachnick & Fidell 1989:87,604,605,640). The remaining 42 variables used in the analysis are listed in Appendix Table A.6.1. 13 of these are identified as transformed to minimise skewnwss and kurtosis according to the finding of normality tests in univariate analysis. Their correlation matrix is recorded in Appendix Table A.6.2.

The suitability of these variables for factor analysis was confirmed by 2 tests applied to each of the 6 factor analyses, the detailed results of which are summarised in

Appendix Table A.6.3: The Bartlett Test of Sphericity indicates that the variables are from a multivariate normal population; the Anti-Image Correlation Matrix and Kaiser-Meyer-Olkin Measure of Sampling Adequacy verify that sampling adequacy is satisfactory. (As an example, details from Analysis 5 only of the Bartlett Test, AIC Matrix/KMO Test and RC matrix are given in Appendix Tables A.6.4, 5 & 6 respectively).

Factors were extracted by Principal Components Analysis, the criterion for the number of factors being eigen value greater than 1. To assist interpretation, Varimax Rotation was applied to the resulting Factor Matrix. Two series of Factor analyses were carried out, one involving all 11 population samples, the other involving only the 7 large sample populations. This seemed advisable in view of the relatively small sizes of the Bushman, Fuegian, Tasmanian and Veddah samples (21, 16, 11 and 18 respectively) and consequent possible sample bias. e.g. possible predominance of robust males in the Fuegian sample. Since a virtually identical pattern emerged in the two series, results from only the eleven group series are presented here. Nevertheless, implications for any of the small groups should be regarded with caution.

A series of analyses was carried out in which the relationship of temporal variables to various combinations of cranial measurements and ratios could be investigated in turn:

1. 18 temporal variables only;
2. 18 temporal variables plus cranial length, breadth and height;
3. 18 temporal variables, cranial length, breadth and height plus cranial base angle and foramen magnum angle;
4. 18 temporal and 6 non-temporal variables, 1 temporal and 4 non-temporal variables being shape ratios;
5. 18 temporal variables plus 7 non-temporal linear variables;
6. 19 temporal variables plus 20 non-temporal variables.

Results are presented in Tables 6.1 - 6.6 as a summary of variable communalities, variable factor loadings and factor variances. A factor loading <.40 was regarded as indicating the factor accounted for insufficient variance (<16%) to be

recorded in the tables. (Tabachnick & Fidell 1989:640). Correlation coefficients quoted are from Appendix Table A.6.1.

In each of the 6 analyses the factor model was found to be appropriate in that

(i) correlation between factors is low. This is indicated by a small number (17% or less) of off-diagonal elements >.09 in the Anti-Image Correlation (AIC) Matrix.

(ii) observed correlations are satisfactorily reproduced by the fitted model. This is indicated by appropriately few (45% or less) residuals >.05 in the Reproduced Correlation (RC) Matrix. Detailed results of these two evaluations are summarised in Appendix Table A.6.3.

6.2 RESULTS AND DISCUSSION I: TEMPORAL VARIABLE RELATIONSHIPS

6.2.1 ANALYSIS 1 HOW ARE TEMPORAL VARIABLES RELATED TO EACH OTHER?

18 temporal variables were involved in the first factor analysis. Results are summarised in Table 6:1.

6.2.1.1 FACTOR 1. Variables showing greatest variability.

Half the temporal measurements, (linear dimensions of the mastoid, temporal squamous, petrous pyramid, tympanic plate, and glenoid fossa), associate in the first principal component and account for 24.2% of the total variance (Table 6.1).

Consideration of relationships among these 9 temporal measurements in the light of their mutual correlation coefficients (Appendix Table A.6.2), indicates that there is strongest relationship between tympanic plate length and glenoid fossa dimensions, and then between these two features and mastoid process dimensions. The correlation of these dimensions with petrous pyramid length and temporal squamous height is weaker. Tympanic height has the lowest correlation of all with the other variables in the Factor 1 association.

Independent of these 9 variables, the remaining temporal variables are nearly all angular measurements. They form 5 factors which account for another 43.4% of the variation and show the associations outlined in Sections 6.2.1.2 - 6.2.1.6.

6.2.1.2 FACTOR 2. Tympanic Sagittal Angle with Ant./Post. Position of Foramen Magnum.

This factor accounts for 12.0% of the total variance. A more anterior position of basion relative to the bitympanic line corresponds to a smaller tympanic plate sagittal angle ($r=-.45$, $p<.001$), (Figure 6.2.1.1a). A similar result was obtained when the position of the foramen magnum centre was considered instead of basion position ($r=-.48$, $p<.001$; Fig.6.2.1.1b). The implication of both results is that the more posteriorly placed the foramen magnum, the more coronally oriented the tympanic plate axis (Fig.6.2.1.2). The tympanic plate appears to accommodate a more anteriorly placed foramen magnum by being more sagitally oriented; this implies that the lateral end of the tympanic plate is more independent of the foramen magnum position than is the medial end.

TABLE 6:1 FACTOR ANALYSIS OF TEMPORAL VARIABLES.

Summary of communalities and factor loadings (> 0.4) of 18 temporal variables for 11 population samples.

VARIABLES	COMM	F1	F2	F3	F4	F5	F6
GLENOID FOSSA MED./LAT. LENGTH	.60	.75					
GLENOID FOSSA ANT/POST. LENGTH	.55	.72					
TYMPANIC PLATE LENGTH	.55	.69					
MASTOID PROCESS DEPTH	.66	.68					
MASTOID PROCESS WIDTH	.68	.66					
MASTOID PROCESS AXIS LENGTH	.77	.66				.55	
TEMPORAL SQUAMOUS HEIGHT	.58	.62					
PETROUS PYRAMID LENGTH	.50	.59					
TYMPANIC PLATE HEIGHT	.45	.51					
TYMPANIC AXIS SAGITTAL ANGLE	.88		.91				
ANTERIORITY OF BASION	.63		-.72				
PETROUS AXIS SAGITTAL ANGLE	.92			.93			
PETROUS-TYMPANIC AXES ANGLE	.95		-.49	.82			
TYMPANIC PLATE ANTERIOR SAGITTAL ANGLE	.59				.71		
TYMPANIC PLATE LATERAL RIM THICKNESS	.70				.71		
TYMPANIC PLATE LATERAL RIM INDENT	.57				-.68		
MASTOID PROCESS AXIS ANGLE	.81					-.87	
EXT.AUDITORY MEATUS AXIS ANGLE	.77						.86

	TOTAL	F1	F2	F3	F4	F5	F6
% VARIANCE accounted for by FACTORS	67.6	24.2	12.0	10.5	8.8	6.2	5.9

6.2.1.3 FACTOR 3. Petrous Pyramid Sagittal Angle and Petrous Pyramid-Tympanic Plate Angle. This factor accounts for 10.5% of the total variance. As petrous sagittal angle increases, the angle between the petrous and tympanic axes increases ($r=.69$, $p<.001$; (Fig.6.2.1.3c & Fig.6.2.1.3a). It might be expected that the tympanic sagittal angle would also appear on this factor because of both its proximity on the cranium to the other two angles and its quite high (negative) correlation with the petrous-tympanic angle ($r=-.57$, $p<.001$; Fig.6.2.1.3b). However, the tympanic angle has its strongest association with anteriority of basion on Factor 2 and does not load significantly (<.4) on Factor 3. Nor is petrous angle found on Factor 2 despite some correlation with tympanic angle ($r=.20$, $p<.001$) and anteriority of basion ($r= -.12$, $p<.001$; Figs.6.2.1.3 c & d). This suggests that, unlike the tympanic angle, the petrous angle is relatively independent of foramen magnum position and to some degree the two angles are determined independently. The higher loading of the petrous-tympanic angle on this factor (.82) compared with its loading on Factor 2 (-.49), suggests it is more strongly related to the petrous angle than to the tympanic angle. However, both loadings are substantial and indicate that the petrous angle is not exclusively associated with either factor 2 or 3 (Fig.6.2.1.3e).

In the investigation referred to in Section 5.3.3.26 of this study, Schulter (1976:453-468) recognised the positive association between petrous sagittal angle and petrous-tympanic angle; she attributed an accompanying negative association with tympanic sagittal angle to the medial end of the tympanic being more readily displaced than the lateral end which is constrained by glenoid fossa dimension requirements. As the petrous axis becomes more coronally oriented the tympanic becomes more sagitally inclined and the petrous-tympanic angle opens out. Schulter found that these angular measurements are independent of other cranial measurements such as overall cranial length, height and breadth, but did not propose a cause of the variation of petrous and tympanic orientation within and between modern human groups nor the change from apes to modern humans (Schulter 1978:465-467).

The results of this study confirm the pattern of relationships between the 3 angles and their independence of

other variables observed by Schulter, and extend it to a wider range of populations. Furthermore, the results suggest one probable cause of the variation is the effect on the tympanic orientation of an anterior placement of the foramen magnum, though clearly other factors are likely to be involved, particularly with respect to petrous orientation.

6.2.1.4 FACTOR 4. Sagittal Angle of the Anterior Side of the Tympanic Plate and Tympanic Lateral Rim Thickness and Indent. This factor accounts for 8.8% of the total variance. The association of these 3 variables indicates that the thicker the tympanic rim, the less indented it is, and the more coronally oriented the anterior side of the tympanic plate.

The relationship between thickness of rim and coronally oriented anterior tympanic side ($r=.33$, $p<.001$) may indicate that expansion of the tympanic plate through thickening is easier in the more open anterior (glenoid fossa) direction than posteriorly towards the mastoid and occipital regions (Fig.6.2.1.4a). The other two relationships seem logical in terms of optimum spatial arrangement: The thicker the tympanic rim, the further it protrudes at the lateral edge, ($r= -28$, $p<.001$; Fig.6.2.1.4b); the more coronally oriented the tympanic, the further it protrudes at the lateral edge, ($r= -30$, $p<.001$; Figs.6.2.1.4c & d).

6.2.1.5 FACTOR 5. Mastoid Process Axis Angle. This factor consists primarily of the angle of the mastoid process axis and accounts for 6.2% of the total variation. Mastoid length, though principally loading on Factor 1 (loading = .66), also shows weaker and negative association with mastoid angle on Factor 5 (Factor 5 mastoid length loading = .55, mastoid angle loading = -.87). The relationship implies that the longer the mastoid process the more acute the mastoid angle, i.e. the more bent forwards the mastoid (Figs.6.2.1.5a & b. See also Section 6.2.6).

6.2.1.6 FACTOR 6. External Auditory Meatus Axis Angle.

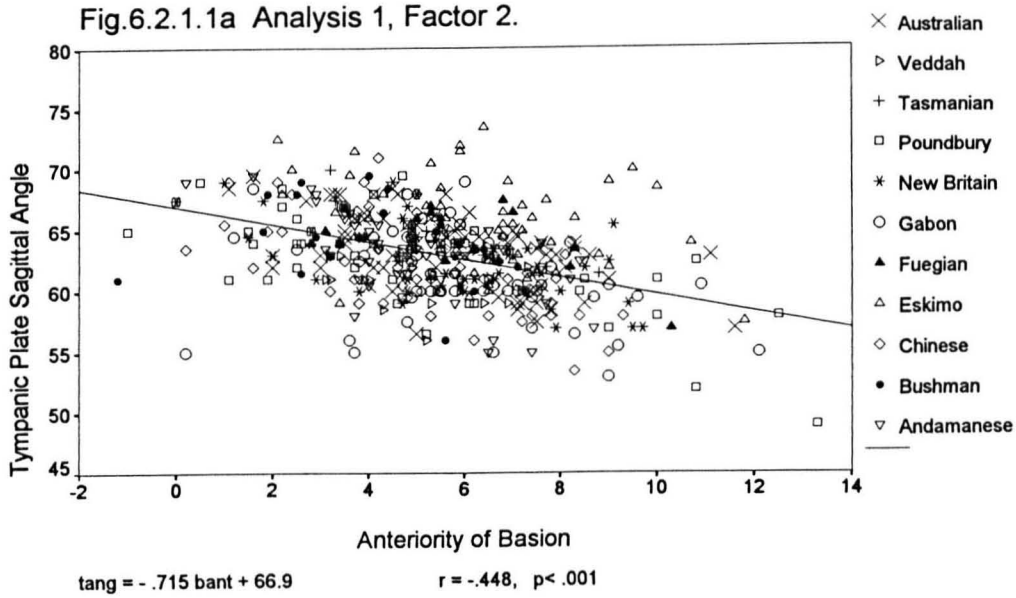
External auditory meatus angle is the only variable to have loading greater than .40 on this last factor, which accounts for 5.8% of the total variance.

6.2.1.7 FACTORS 1-6.

Altogether, these six factors account for just over two thirds (67.6%) of the total variance in the sample's temporal bone measurements. Except for tympanic plate rim thickness and indent and the position of basion relative to the bitympanic line, the temporal linear dimensions appear to have a common association and be independent of temporal angular measurements. Most of the angular measurements also show independence of each other.

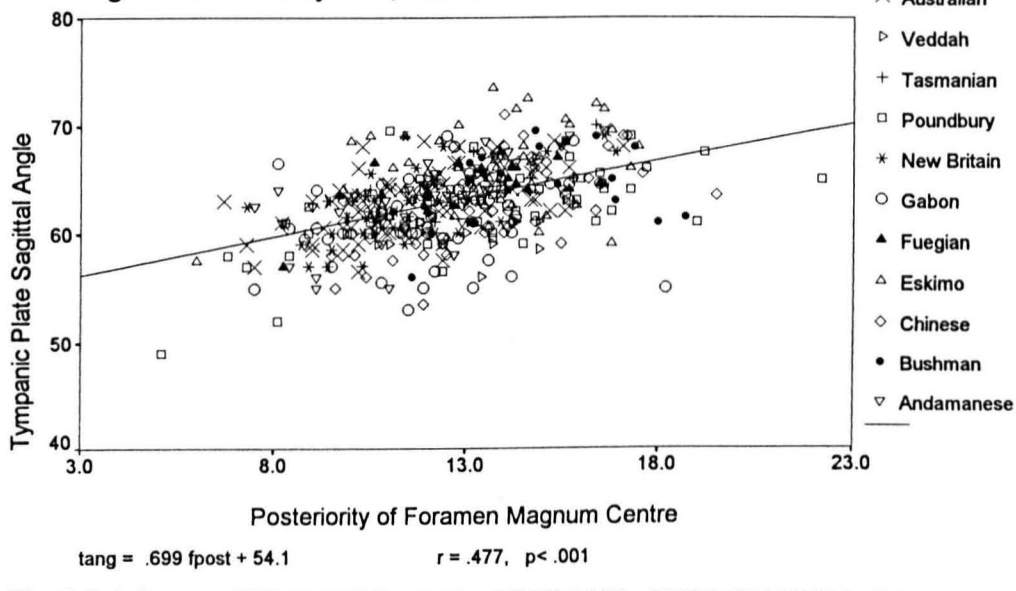
Factors 2, 3, 5 & 6 must be regarded as poorly defined since each comprises only 1 or 2 variables with significantly high factor loadings(>.40). Also the presence of complex variables (mastoid process length and petrous/tympanic angle both have significantly high loadings on more than one factor) indicates the factor structure is not simple.

Fig.6.2.1.1a Analysis 1, Factor 2.



tang = - .715 bant + 66.9 r = -.448, p< .001

Fig.6.2.1.1b Analysis 1, Factor 2.



tang = .699 fpost + 54.1 r = .477, p< .001

Fig.6.2.1.2 TYMPANIC AND PETROUS ORIENTATION IN RELATION TO THE FORAMEN MAGNUM POSITION.

B=basion; FM=foramen magnum; MP=mastoid process;
P=petrous axis sagittal angle; T=tympanic axis sagittal angle;
PT=petrous-tympanic angle; X=basion anteriority.

$$T_1 > T_2,\ P_1 > P_2,\ X_1 < X_2,\ PT_1 < PT_2.$$

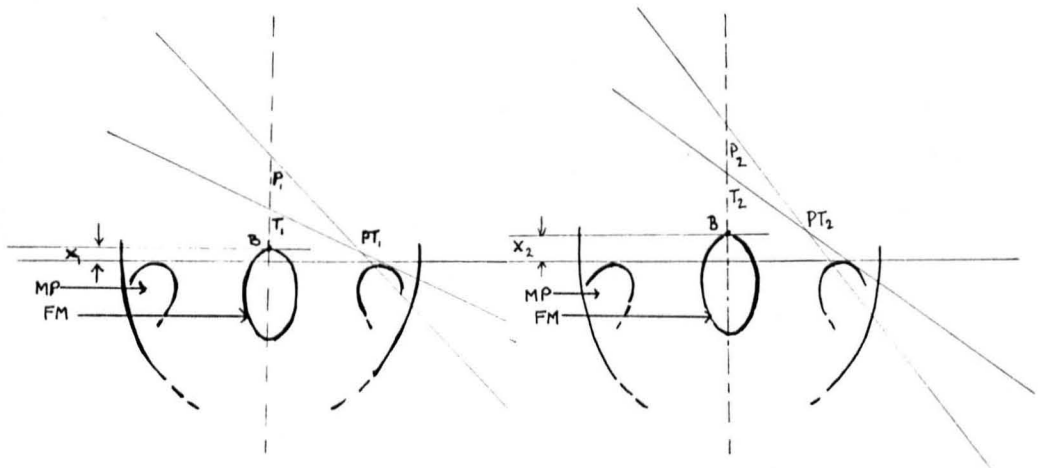
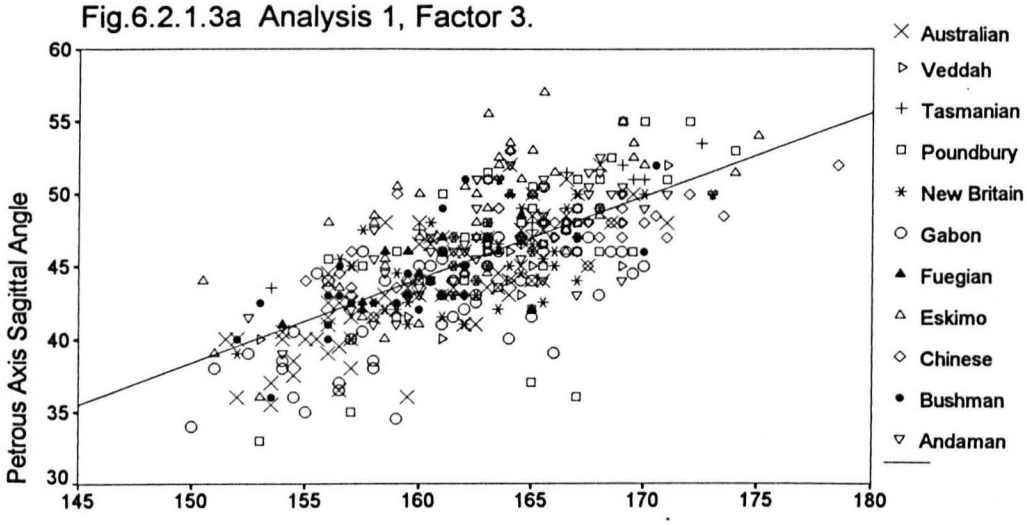
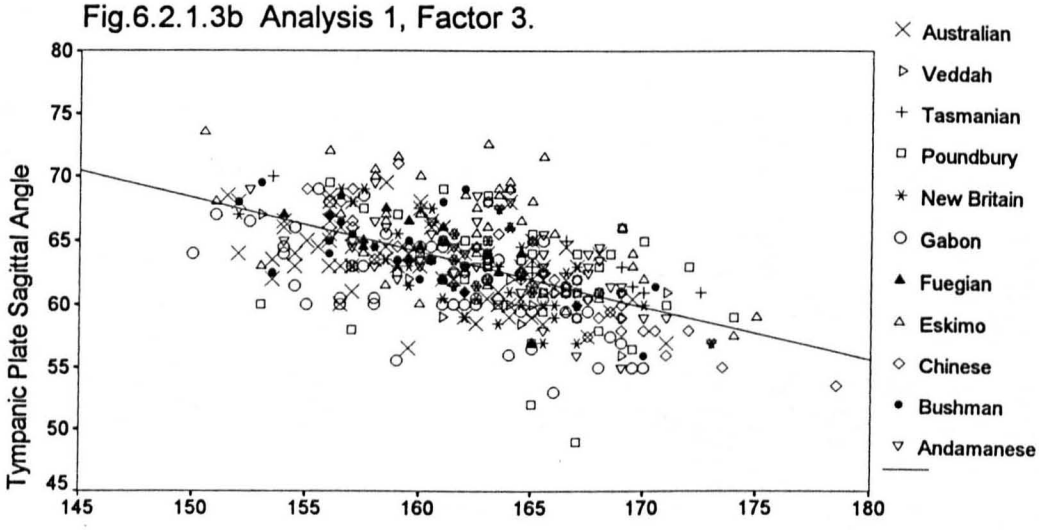


Fig.6.2.1.3a Analysis 1, Factor 3.



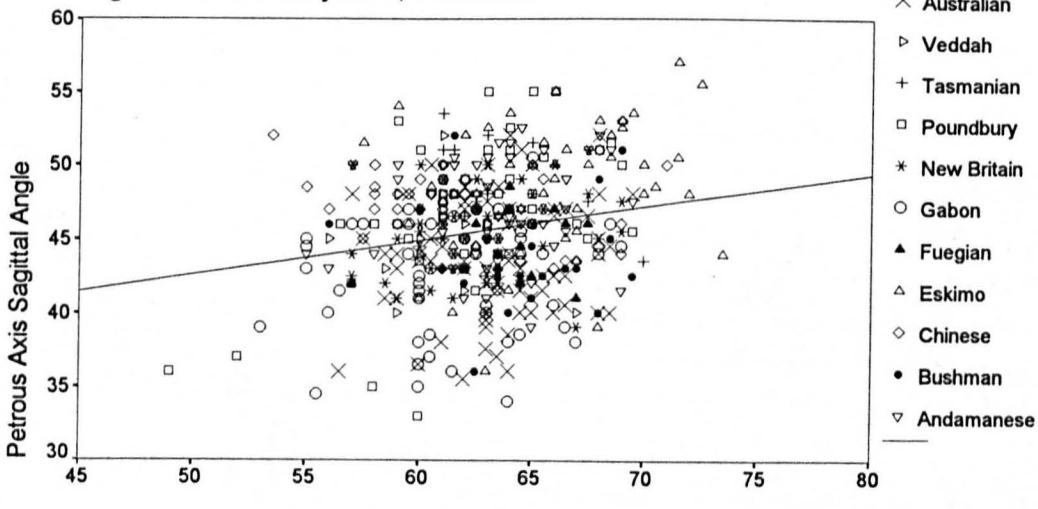
pangs = .575 ptang - 47.9 r = .687, p< .001

Fig.6.2.1.3b Analysis 1, Factor 3.



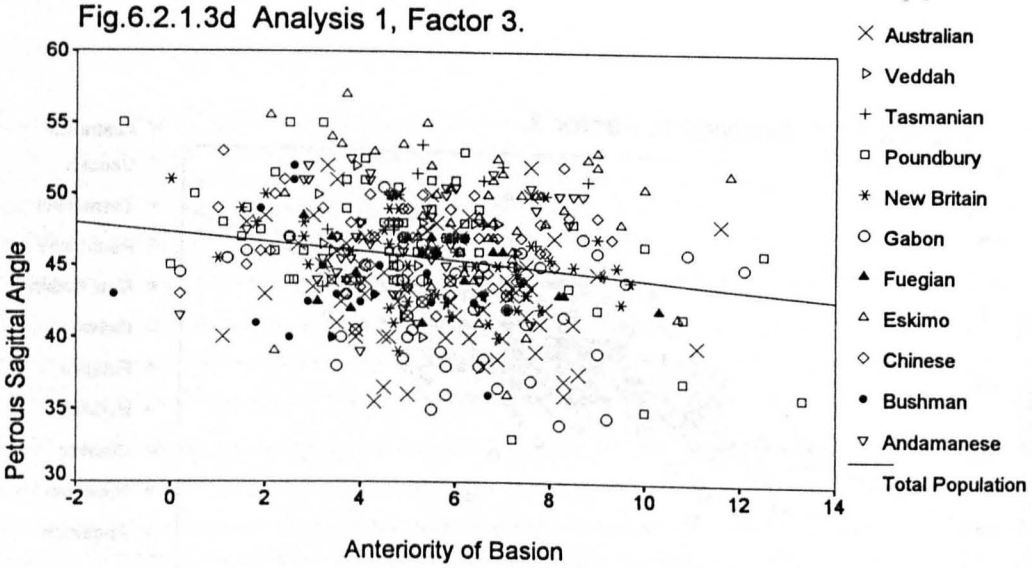
tangs = -.424 ptang + 131.9 r = -.572, p< .001

Fig.6.2.1.3c Analysis 1, Factor 3.



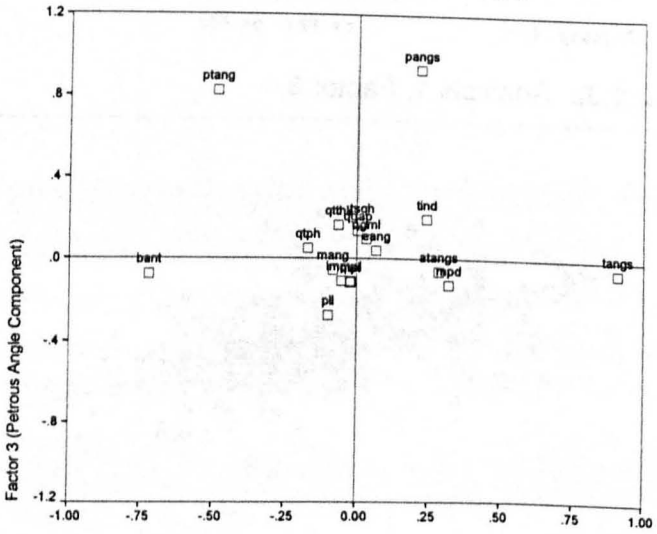
pangs = .227 tangs + 31.3 r = .201, p< .001

Fig.6.2.1.3d Analysis 1, Factor 3.



pangs = - .320 bant + 47.3 r = - .178, p< .001

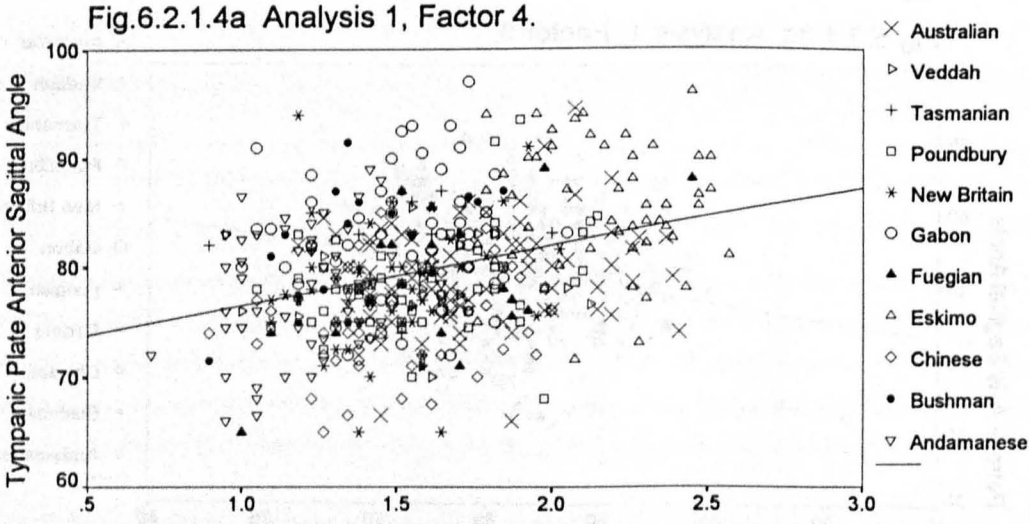
Fig.6.2.1.3e Analysis 1, Factor 3 vs. Factor 2



Petrous-tympanic angle on F3 is also strongly related to F2.

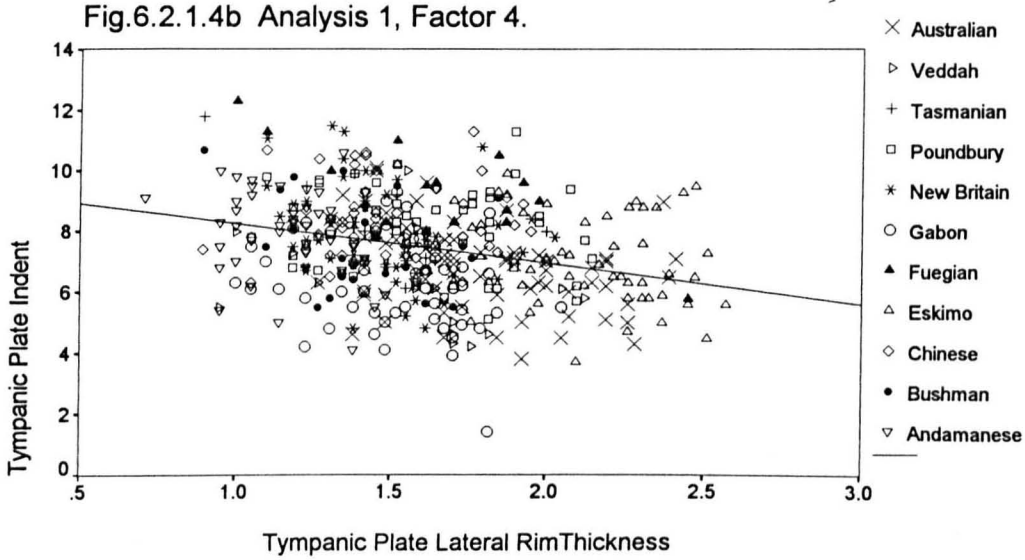
Petrous angle on F3 shows more independence from F2.

Fig.6.2.1.4a Analysis 1, Factor 4.



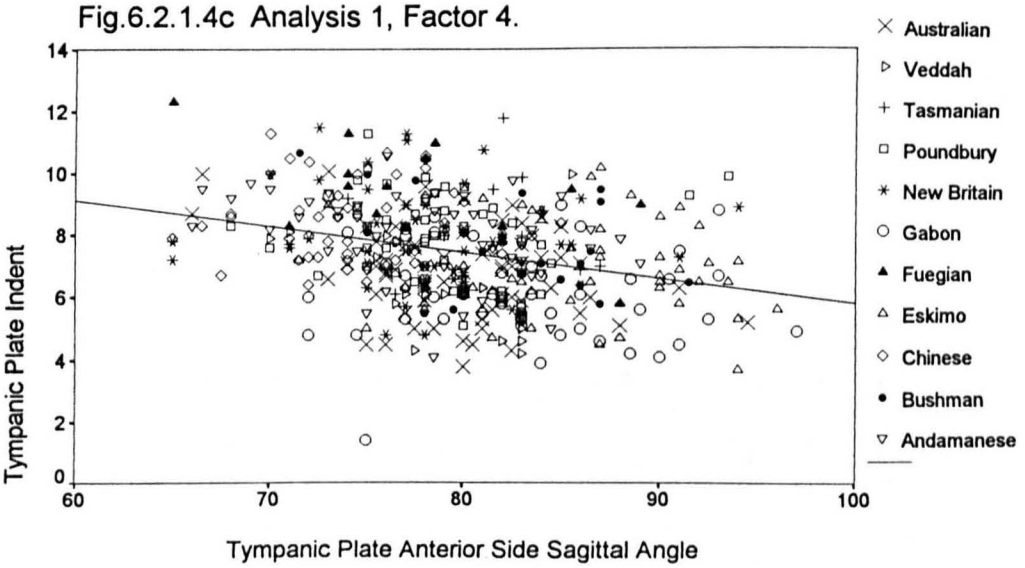
atang = 5.38 tthk + 71.1 r = .330, p< .001

Fig.6.2.1.4b Analysis 1, Factor 4.



tind = -1.31 tthk + 9.57 r = -.288, p< .001

Fig.6.2.1.4c Analysis 1, Factor 4.



tind = -.084 atang + 14.1 r = -.298, p< .001

Fig.6.2.1.4d RELATIONSHIP BETWEEN THE TYMPANIC PLATE LATERAL RIM INDENT AND THE SAGITTAL ANGLE OF THE TYMPANIC PLATE ANTERIOR SIDE.

AT = sagittal angle of anterior side of tympanic plate;
FM = foramen magnum; MP=mastoid process; TP = tympanic plate.

$AT_1 > AT_2$, $Indent_1 < Indent_2$.

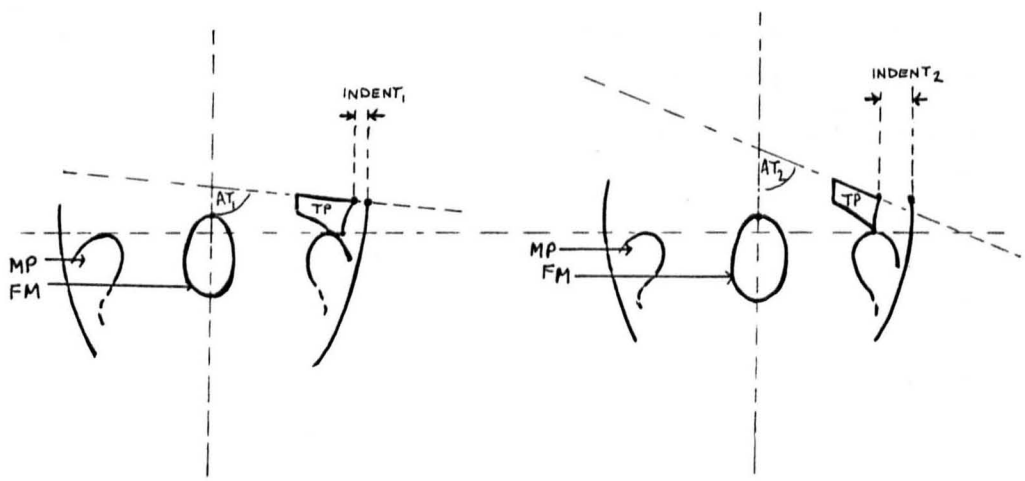
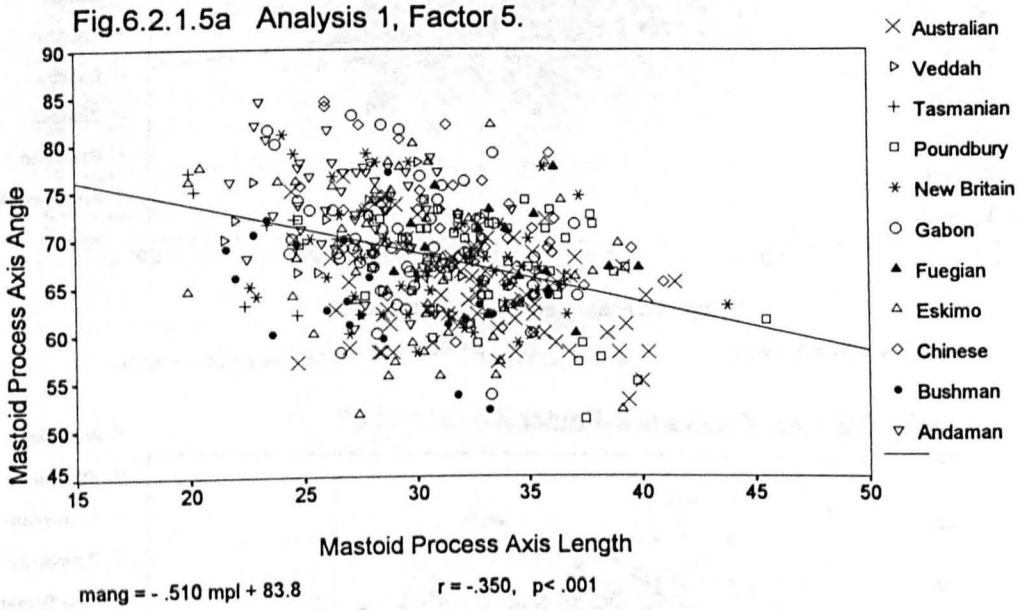


Fig.6.2.1.5a Analysis 1, Factor 5.

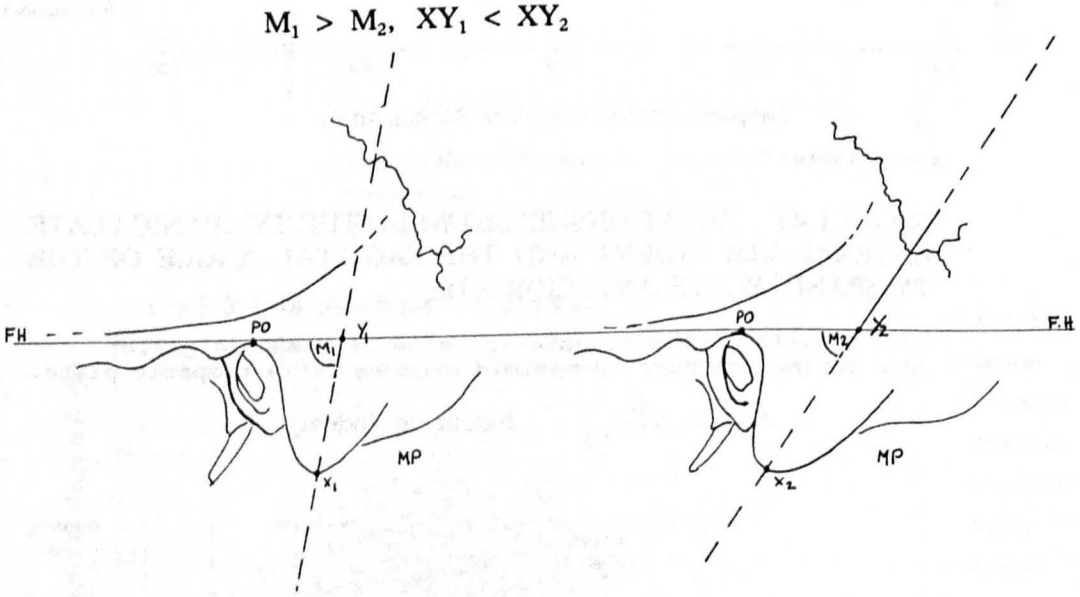


mang = - .510 mpl + 83.8 r = -.350, p< .001

Fig.6.2.1.5b RELATIONSHIP BETWEEN THE ANGLE AND LENGTH OF THE MASTOID PROCESS AXIS.

FH=Frankfurt Horizontal; M=mastoid angle; MP=mastoid process; PO=porion; XY=length of mastoid axis.

$M_1 > M_2,\ XY_1 < XY_2$



6.2.2 ANALYSIS 2.

HOW ARE TEMPORAL VARIABLES RELATED TO OVERALL CRANIAL SIZE?

In the second analysis, variables representing overall cranial length, breadth and height were included with the 18 temporal variables to investigate how temporal variables would assort with variables which measure dimensions of overall cranial size.

The pattern of temporal variable associations found in the first analysis reappear here (Table 6.2), but in addition the 3 size-related variables of cranial length, breadth and height associate on the first factor with the nine linear temporal measurements; all correlations are positive. This implies that

(i) these 9 linear temporal variables, (mastoid length, width and depth, tympanic plate length and height, glenoid fossa depth, anterior/posterior length and medial/lateral length, petrous pyramid length and temporal squamous height) are dependent to some degree on overall cranial size;

(ii) the temporal angular measurements and 3 remaining linear dimensions are relatively independent of overall cranial size, though tympanic rim thickness did show a weak secondary loading of .40 on the first size factor.

Figs.6.2.2.1-4 show the comparative independence of factors 2-5 and their component variables from the first size-related factor.

Compared to the first analysis, the amount of total variance accounted for by the first size-related factor has increased to 28.7%, but the total variance accounted for by the six factors remains virtually the same at 67.4%. Analyses 5 and 6 contain more overall cranial size variables and shed further light on the size relatedness of temporal variables.

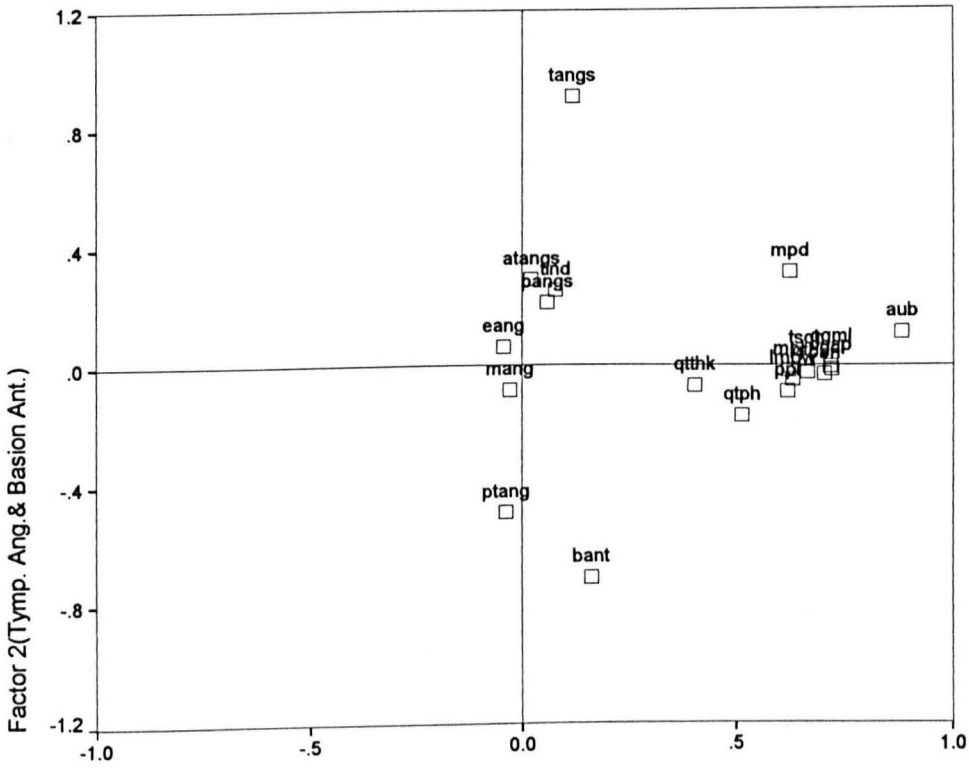
TABLE 6:2 FACTOR ANALYSIS OF TEMPORAL AND OVERALL CRANIAL SIZE VARIABLES.

Summary of communalities and factor loadings (> 0.4) of 18 temporal variables and 3 overall cranial size variables for 11 population samples.

VARIABLES	COM	F1	F2	F3	F4	F5	F6
BIAURICULAR BREADTH	.87	.88					
GLABELLA-OPISTHOCRANION LENGTH	.70	.72					
GLENOID FOSSA MED/LAT.LENGTH	.57	.72					
GLENOID FOSSA ANT/POST. LENGTH	.54	.72					
BREGMA-BASION CRANIAL HEIGHT	.62	.70					
TYMPANIC PLATE LENGTH	.52	.66					
TEMPORAL SQUAMOUS HEIGHT	.59	.66					
MASTOID PROCESS WIDTH	.68	.63					
MASTOID PROCESS DEPTH	.64	.62					
MASTOID PROCESS AXIS LENGTH	.76	.62				.56	
PETROUS PYRAMID LENGTH	.52	.62					
TYMPANIC PLATE HEIGHT	.41	.53					
TYMPANIC AXIS SAGITTAL ANGLE	.88		.91				
ANTERIORITY OF BASION	.63		-.72				
TYMPANIC PLATE ANT.SAG.ANGLE	.60			.71			
TYMPANIC PLATE LATERAL RIM INDENT	.60			-.68			
TYMPANIC PLATE LATERAL RIM THICKNESS	.67	.40		.66			
PETROUS AXIS SAGITTAL ANGLE	.90				.92		
PETROUS-TYMPANIC AXES ANGLE	.94		-.50		.81		
MASTOID PROCESS AXIS ANGLE	.80					-.87	
EXT.AUDIT. MEATUS AXIS ANGLE	.72						.83

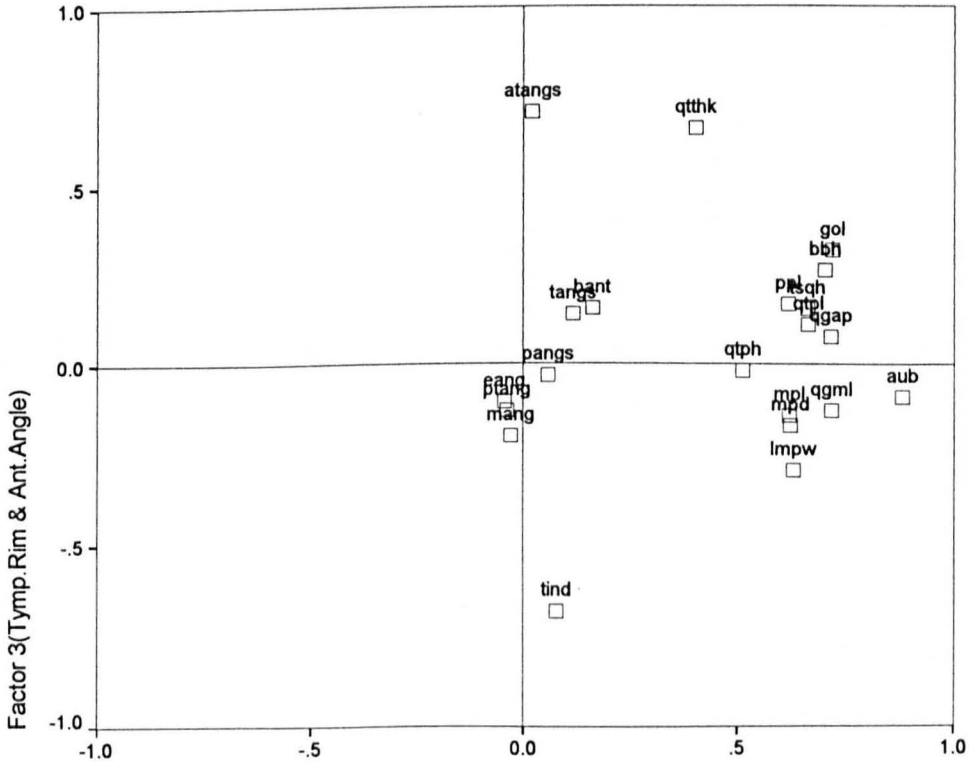
	TOTAL	F1	F2	F3	F4	F5	F6
% VARIANCE accounted for by FACTORS	67.4	28.7	10.5	9.3	7.9	5.7	5.3

Fig.6.2.2.1 Factor 2 vs. Factor 1, Analysis 2



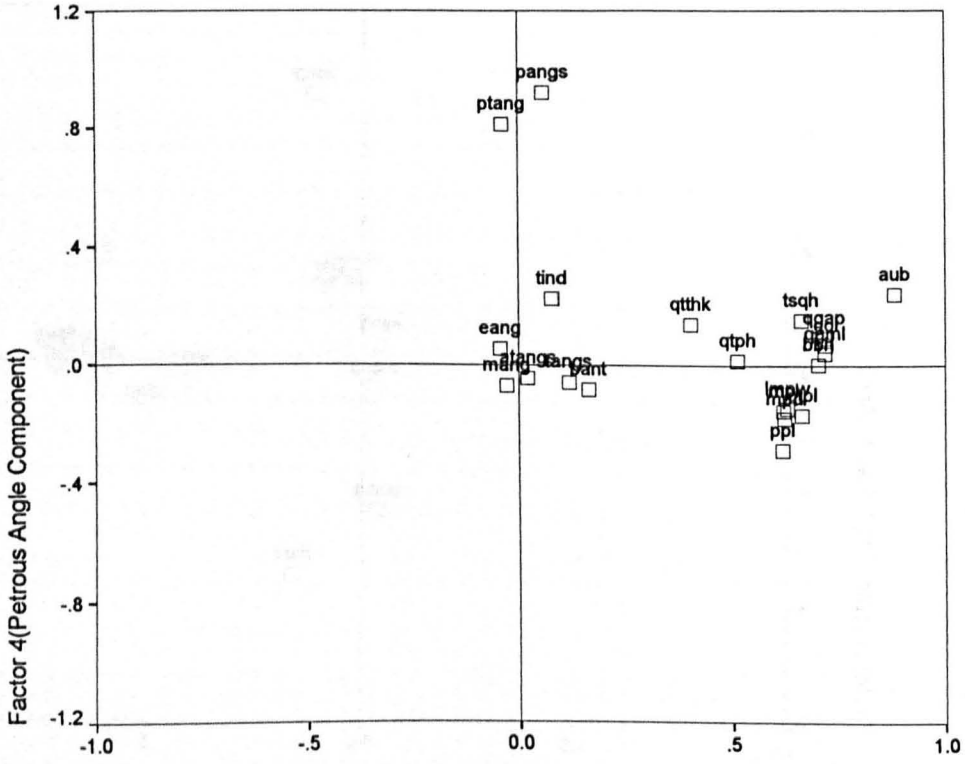
Tympanic angle(tangs) & basion anteriority(bant) on F2,show independence from F1. Petrous-tympanic angle(on F4) shows some association with F2.

Fig.6.2.2.2 Factor 3 vs. Factor 1, Analysis 2



Tympanic rim indent (tind) & ant.angle (atangs) on F3 are independent of F1.Tympanic rim thickness (qtthk) shows some link with size-related F1.

Fig.6.2.2.3 Factor 4 vs. Factor 1, Analysis 2

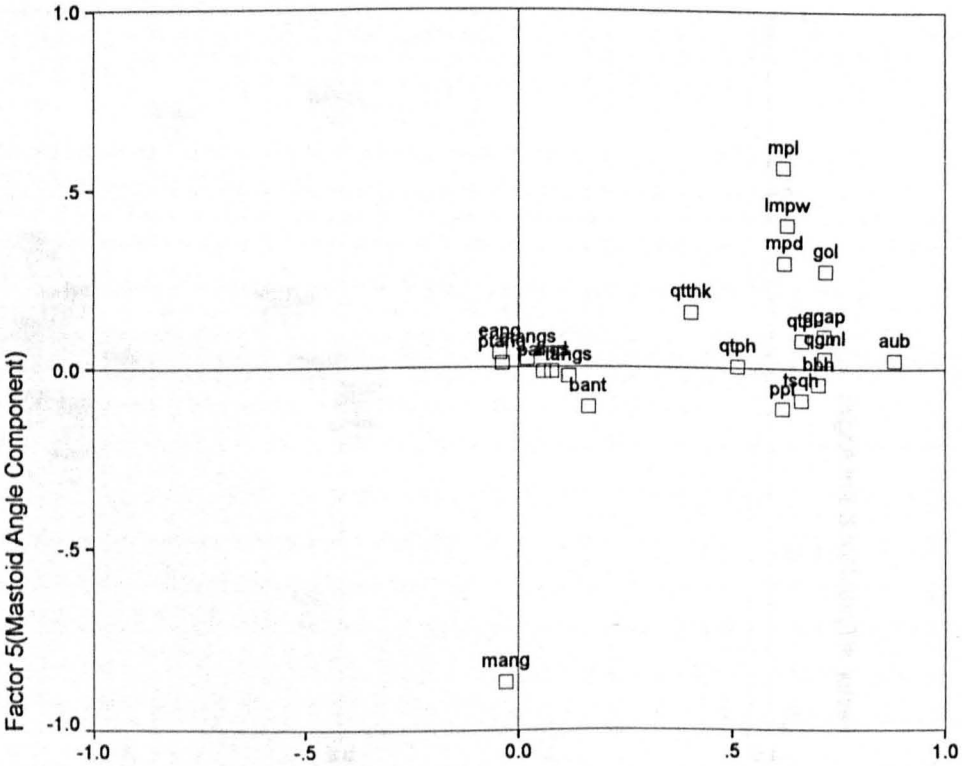


Factor 1 (Size Component)

Petrous angle (pangs) & petrous-tympanic angle (ptang) on F4 show

independence from F1.

Fig.6.2.2.4 Factor 5 vs. Factor 1, Analysis 2



Factor 1 (Size Component)

Mastoid angle (mang) on F5 shows independence from F1.

Mastoid length is more closely associated with F1.

6.2.3 ANALYSIS 3.

HOW ARE TEMPORAL VARIABLES RELATED TO BASE ANGULATION ?

To investigate possible relationship of temporal variables to basicranial angulation, the variables base flexion angle (represented by the staphylion-hormion-basion angle) and foramen magnum angle (represented by staphylion-basion-opisthion angle) were added to the variables in the previous analysis.

Results summarised in Table 6.3 show the same general pattern that emerged in the first two analyses except that the foramen magnum angle joined the mastoid angle in a positive association on Factor 5. This suggests that a more vertically inclined mastoid axis may correspond to a more vertically oriented foramen magnum (Fig.6.2.3.1a). If so, the possibility arises of a connection between brain expansion and mastoid axis orientation since a downwards and forwards rotation of the foramen magnum is thought to be a consequence of brain expansion both during human post natal growth and in the course of hominid evolution (Aiello & Dean, 1990:164,165). Factor 5 accounted for only 5.8% of the total variance. The correlation between the 2 angles is significant but very low ($r=.17$, $p<.001$) and the relationship was too weak to be immediately evident in the bivariate plot (Fig.6.2.3.1b).

The cranial base flexion angle was grouped with variables in the size-related first factor but with such a weak association that its factor loading was less than 0.4. It did not associate with any other temporal variables in other factors nor, as might have been expected, with the foramen magnum angle. Therefore, apart from a weak mutual connection through overall cranial size, temporal variables appear to be independent of base flexion as measured by staphylion-hormion-basion angle.

TABLE 6:3 FACTOR ANALYSIS OF TEMPORAL, OVERALL CRANIAL SIZE AND BASE ANGULATION VARIABLES.

Summary of communalities and factor loadings (> 0.4) of 18 temporal variables and 5 non-temporal variables (overall cranial size and base angulation) for 11 population samples.

VARIABLES	COM	F1	F2	F3	F4	F5	F6
BIAURICULAR BREADTH	.87	.87					
GLABELLA-OPISTHOCRANION LENGTH	.71	.73					
BREGMA-BASION CRANIAL HEIGHT	.76	.72					
GLENOID FOSSA MED/LAT.LENGTH	.57	.72					
GLENOID FOSSA ANT/POST. LENGTH	.54	.71					
TYMPANIC PLATE LENGTH	.52	.66					
MASTOID PROCESS WIDTH	.66	.66					
MASTOID PROCESS AXIS LENGTH	.73	.66					
TEMPORAL SQUAMOUS HEIGHT	.51	.64					
MASTOID PROCESS DEPTH	.64	.64					
PETROUS AXIS LENGTH	.50	.61					
TYMPANIC PLATE HEIGHT	.41	.52					
BASE FLEXION ANGLE	.35	< .40					
TYMPANIC PLATE ANT.SAG.ANGLE	.57		.69				
TYMPANIC PLATE LATERAL RIM INDENT	.59		-.69				
TYMPANIC PLATE LATERAL RIM THICKNESS	.69		.66				
TYMPANIC AXIS SAGITTAL ANGLE	.84			.88			
ANTERIORITY OF BASION	.68			-.76			
PETROUS AXIS SAGITTAL ANGLE	.89				.91		
PETROUS-TYMPANIC AXES ANGLE	.89			-.47	.79		
FORAMEN MAGNUM ANGLE	.65					.74	
MASTOID PROCESS AXIS ANGLE	.66					.67	
EXT.AUDIT. MEATUS AXIS ANGLE	.49						.68

	TOTAL	F1	F2	F3	F4	F5	F6
% VARIANCE accounted for by FACTORS	64.0	26.6	10.2	8.8	7.3	5.8	5.1

Fig.6.2.3.1a
RELATIONSHIP BETWEEN THE ORIENTATION OF THE FORAMEN MAGNUM AND THE ANGLE OF THE MASTOID PROCESS AXIS.
B=basion; FH=Frankfurt Horizontal; F=foramen magnum angle; M=mastoid angle; MP=mastoid process; O=opisthion; OR=orbitale; PO=porion; S=staphylion.

$F_1 < F_2, \qquad M_1 < M_2$

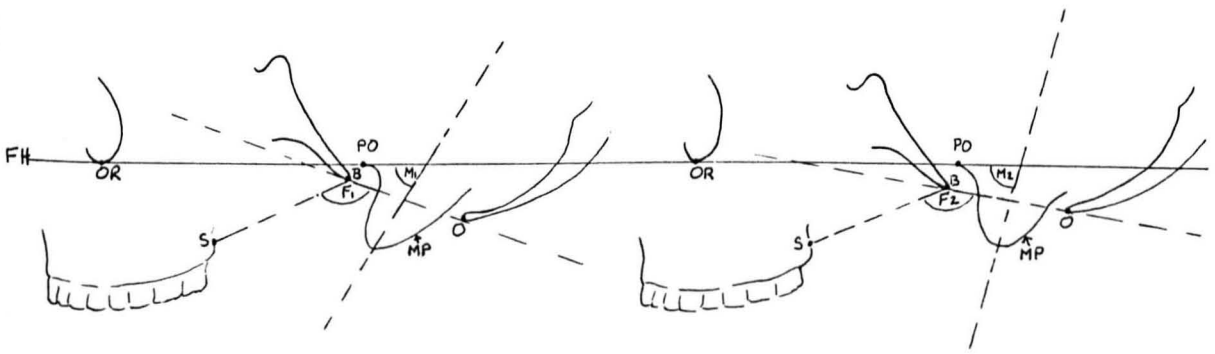
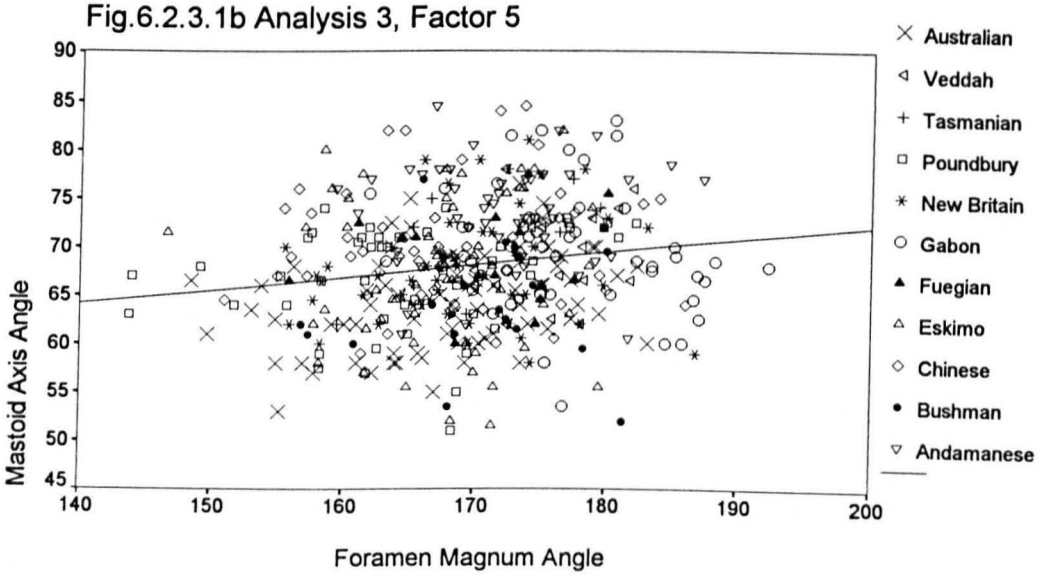


Fig.6.2.3.1b Analysis 3, Factor 5



MANG = .133 FANG + 45.5 r = .165, p< .001

6.2.4. ANALYSIS 4.

HOW ARE TEMPORAL VARIABLES RELATED TO SHAPE VARIABLES ?

This analysis investigates how temporal variables associate with several (7) variables which describe overall cranial shape or shape of a number of cranial features. These shape-related variables are not necessarily independent of cranial size. However, the correlation coefficients of the variables with cranial size[1] show that all but one, cranial breadth ratio*, have weak to negligible association with cranial size at p<.001 (Appendix Tables A.5.4 & 7; Section 5.1,2).

cranial breadth:length ratio (SMCGOL)....	r= .07 , p>.01)
s.crest:parietal breadth ratio (SCXCB)...	*r= .56, p<.001)
glenoid fossa length:width ratio (GFIDX).	r= .12, p=.01)
nasal width:height ratio (NBHX).....	r=-.36, p<.001)
occipital chord ratio (OIX).....	r=-.13, p<.001)
endinion-inion separation (ENIN).....	r=-.34, p<.001)
opisthocranion-inion separation (OCNINA).	r=-.016, p>.01)

Of the 18 temporal variables in the previous analyses, the 2 glenoid fossa dimensions have been combined in this analysis to form the single variable, glenoid fossa ratio. The total number of temporal variables is maintained at 18 by the addition of suprameatal crest angle. Altogether, Analysis 4 includes 6 non-temporal shape ratios, 1 temporal shape ratio and 17 other temporal variables. Cranial length, breadth and height have not been included. The resulting factor matrix shows essentially the same pattern of relationships among temporal variables as in Analysis 1, but 2 new factors and a few additional associations are incorporated (Table 6.4).

Except for the absence of 2 glenoid fossa dimensions, width and length, Factor 1 comprises the same temporal variables indicated as size-related in the previous analyses. No additional variables associate with Factor 1 and the total variance it accounts for falls to 17.4%.

The 3 occipital variables associate strongly to form a new factor (Factor 2), which accounts for 9.6% of the total variance. These occipital variables thus show independence from all temporal variables including those linked to size in

[1] Cranial Size(LBH) = $\frac{1}{100}$ x cub.root[GOL x AUB x BBH]

TABLE 6:4

FACTOR ANALYSIS OF TEMPORAL AND SHAPE VARIABLES.

Summary of communalities and factor loadings (> 0.4) of 17 temporal linear variables and 7 shape-related variables for 11 population samples.

VARIABLES	COM	F1	F2	F3	F4	F5	F6	F7	F8
MASTOID PROCESS LENGTH	.77	.78							
MASTOID PROCESS WIDTH	.71	.76							
MASTOID PROCESS DEPTH	.64	.66							
TYMPANIC PLATE LENGTH	.50	.64							
PETROUS PYRAMID LENGTH	.53	.64							
TEMPORAL SQUAMOUS HEIGHT	.61	.61							
TYMPANIC PLATE HEIGHT	.48	.61							
LAMBDA-INION/INION-OPISTHION RATIO	.76		.85						
ENDINION-INION SEPARATION	.74		.81						
OPISTHOCRANION-INION ARC	.61		.69						
TYMPANIC AXIS SAGITTAL ANGLE	.86			.91					
ANTERIORITY OF BASION	.66			-.71					
TYMP.PLATE LAT.RIM INDENT	.64				.76				
TYMPANIC PLATE ANTERIOR SAGITTAL ANGLE	.59				-.62				
CRANIAL BRDTH./LGTH. RATIO	.70				.60				
TYMPANIC PLATE LATERAL RIM THICKNESS	.72				-.58		.41		
PETROUS AXIS SAG. ANGLE	.88					.90			
PETROUS-TYMPANIC AXES ANGLE	.94			-.51		.80			
NASAL WIDTH/HEIGHT RATIO	.53					-.46			
GLENOID FOSSA ~~WDTH~~/~~LGTH~~ RATIO	.65						.71		
SUPRAMEATAL CREST ANGLE	.68						.65		
BI S.CREST BDTH/MAX.PAR.BDTH.	.61	.45					.50		
MASTOID PROCESS AXIS ANGLE	.70							.80	
EXT.AUD.MEATUS AXIS ANGLE	.58								.87

% VARIANCE	TOTAL	F1	F2	F3	F4	F5	F6	F7	F8
accounted for by FACTORS	67.8	17.4	9.6	9.2	9.0	7.2	6.1	4.9	4.4

Analysis 2. The positive association between the occipital variables indicates that as the occipital chord ratio decreases (i.e. the occipital plane below inion lengthens relative to that above inion)

(i) opisthocranion-inion separation decreases, i.e. opisthocranion is found closer to inion ($r=.39$, $p<.001$); and

(ii) endinion-inion separation decreases, i.e. endinion is found less far above inion ($r=.62$, $p<.001$; Figs.6.2.4.1a & b).

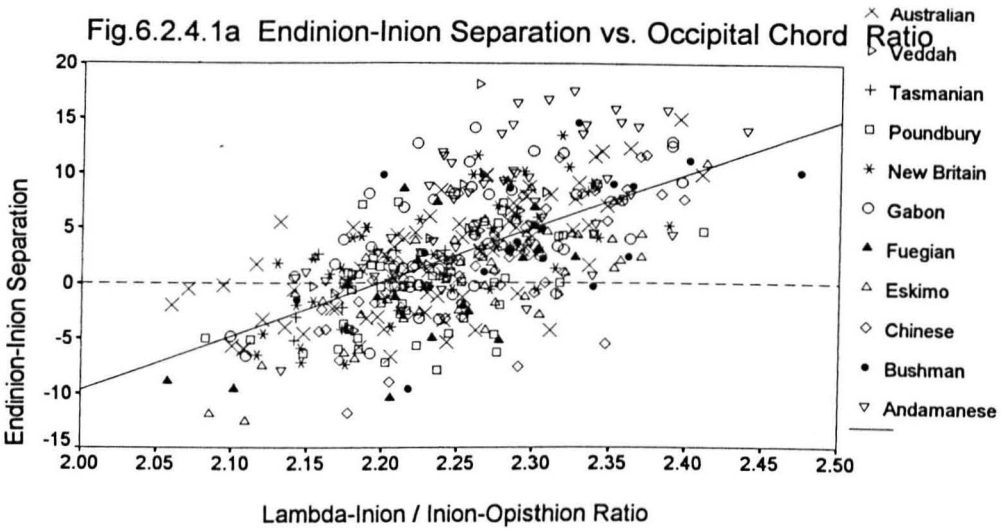
The fact that endinion-opisthion chord has negligible correlation with the occipital chord ratio ($r=-.097$, $p>.01$) and little with inion-opisthion chord ($r=.17$, $p<.01$) suggests that the position of endinion relative to opisthion is determined by different causes than those determining the position of inion relative to opisthion. It is possible that a large nuchal plane, as indicated by a large inion-opisthion chord, may correlate with large nuchal musculature. If so, the relationships in this factor suggest that a large nuchal musculature is also associated with a small opisthocranion-inion separation and a high inion relative to endinion.

On Factor 4, cranial breadth to length ratio joins the 3 variables, tympanic plate lateral rim thickness and indent and tympanic anterior sagittal angle. This factor accounts for 9.0% of the total variance. From the correlation coefficients, the strongest link is through the degree of indent of the tympanic plate ($r=.40$, $p<.001$). Crania which are narrow compared to length tend to have more protruding tympanic lateral rims (Figs.6.2.4.2a & b). Less expected is the cranial breadth/length ratio's negative, though weak, association with anterior tympanic sagittal angle ($r= -.13$, $p<.01$) and lateral rim thickness ($r=-.17$, $p<.001$).

Nasal width to height ratio shows a negative association on Factor 5 with petrous sagittal angle ($r= -.24$, $p<.001$) and petrous-tympanic angle ($r= -.16$, $p<.001$). The weakness of the association is evident from the low correlation coefficients and factor loading (-.46). This factor accounts for 7.2% of the total variance.

On Factor 6, glenoid fossa ratio and suprameatal crest angle have the highest loadings (.71 & .65 respectively), but correlation between the 2 variables is low ($r= .15$, $p<.01$).

Fig.6.2.4.1a Endinion-Inion Separation vs. Occipital Chord Ratio



endin = 49.0 loix - 107.7 r = .62, p = .001

Co-ords.above y=0 are of crania with endinion above inion.

Fig.6.2.4.1b RELATIONSHIP BETWEEN ENDINION-INION SEPARATION, INION-OPISTHOCRANION SEPARATION AND LAMBDA-INION/INION-OPISTHION RATIO.

e = endinion; i = inion; L = lambda; O = opisthion; OCN = opisthocranion.

$(e_1-O_1) - (i_1-O_1) > (e_2-O_2) - (i_2-O_2)$, [chords]

$(OCN_1-i_1) > ((OCN_2-i_2)$, [arcs]

$(L_1-i_1) / (i_1-O_1) > (L_2-i_2)/(i_2-O_2)$. [chords]

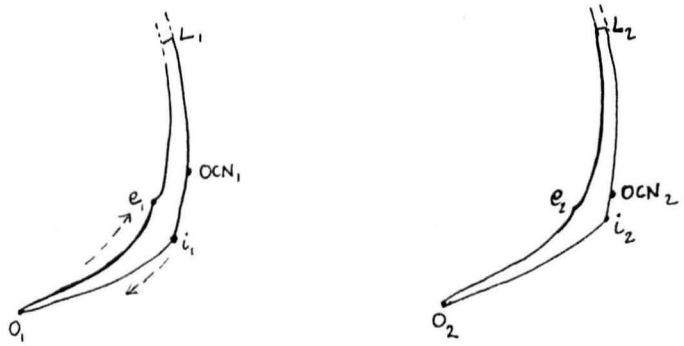
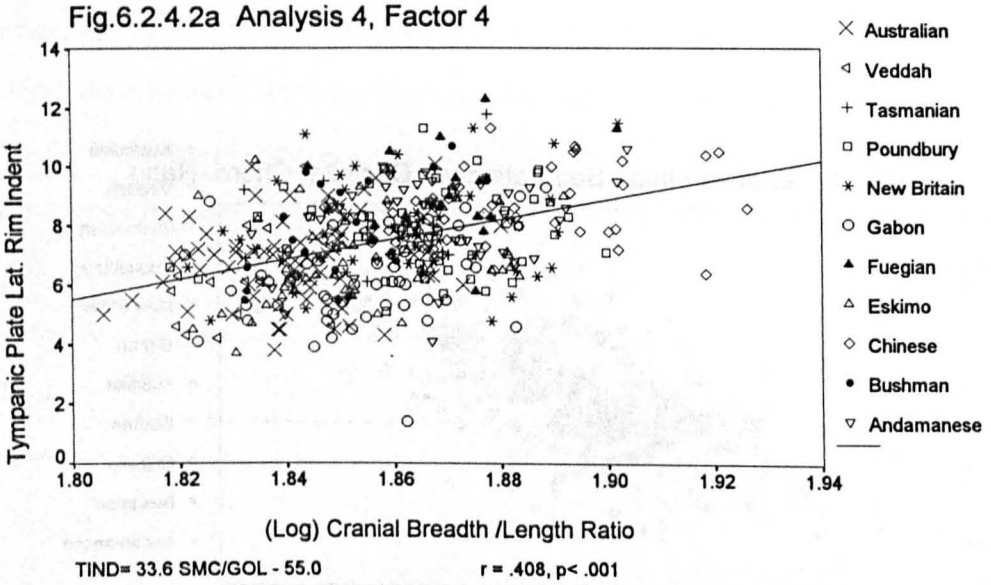


Fig.6.2.4.2a Analysis 4, Factor 4



TIND= 33.6 SMC/GOL - 55.0 r = .408, p< .001

Fig.6.2.4.2b RELATIONSHIP BETWEEN THE CRANIAL BREADTH/LENGTH RATIO AND THE TYMPANIC PLATE LATERAL RIM INDENT.

The larger the cranial breadth/length ratio, the larger the tympanic plate lateral rim indent.

XY=indent of tympanic plate lateral rim.

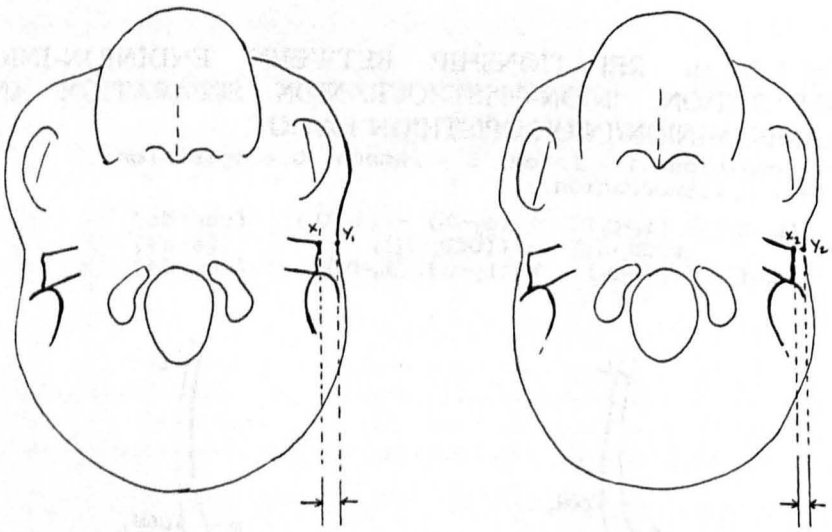
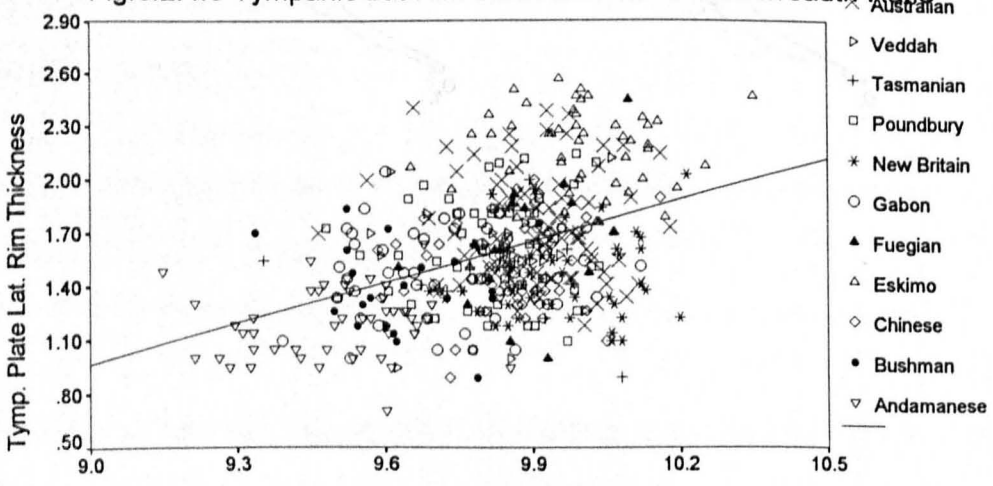


Fig.6.2.4.3 Tympanic Lat.Rim Thickness vs. Cranial Breadth Ratio



QTTHK = .77 SMCXCB - 5.98 r = .42, p = .001

Cranial breadth ratio and tympanic rim thickness also contribute a positive, but weaker association (loadings of .50 & .41 respectively). Correlation values make it clear that cranial breadth ratio and tympanic rim thickness are linked more strongly to each other, ($r=.42$, $p<.001$), than either is to glenoid fossa shape ($r=.14$, $p<.01$; $r=.22$, $p<.001$) or to suprameatal crest angle ($r=.23$, $p<.001$; $r=.14$, $p<.01$). The cranial breadth ratio also shows a weak association with the first factor (loading .45), consistent with its significant correlation with mastoid dimensions, e.g. with mastoid depth, $r=.37$, $p<.001$. Crania with thick tympanic rims and large mastoid processes tend to be those which are relatively broad at the supramastoid crest level (Fig.6.2.4.3). Factor 6 accounts for 6.1% of the total variance.

As seen from the correlation coefficients given above, there is little association between glenoid fossa shape and cranial breadth ratio. Apart from weak links with tympanic rim thickness ($r=.22, p<.001$) and suprameatal crest angle ($r=.15, p<.01$), glenoid fossa shape as measured here is independent of other temporal variables.

SUMMARY:

Analysis 4 results show that for temporal variables

* none are related to the 3 occipital variables;
* petrous angle and petrous-tympanic angle have weak association with nasal width/height ratio; the wider the nasal aperture the more acute the two angles.
* tympanic rim thickness and indent, and anterior sagittal angle relate to cranial length/breadth ratio; a long, thin cranium tends to have a tympanic plate with coronally inclined anterior side and thick, protruding rim.
* tympanic rim thickness has weak positive association with cranial breadth ratio, glenoid fossa ratio and suprameatal crest angle; a thick tympanic rim is associated with a cranium which has a low maximum breadth, a large suprameatal crest angle and large glenoid fossa length-to-width ratio.

6.2.5. ANALYSIS 5. HOW ARE TEMPORAL VARIABLES RELATED TO LINEAR NON-TEMPORAL VARIABLES?

Investigation of the relationship of temporal variables to non-temporal linear measurements was extended beyond the 3 variables included in Analysis 2 (cranial length, breadth and height) to a further 4 which were thought to differ considerably from one population to another and may be comparatively unrelated to cranial size. The added variables are maximum parietal breadth, foramen magnum length and breadth and nasal width.

Analysis 5 yields the same basic pattern of relationships (Table 6.5), but with the following alterations:

The second factor as well as the first relates to overall cranial size. Cranial height and the two variables measuring overall cranial breadths (biauricular and biparietal) have their highest loadings on Factor 1; overall cranial length is on Factor 2. The linear temporal variables which in Analyses 1-4 had appeared together in the first factor now have divided into two groups. Those aligned with cranial breadth on the first factor are the mastoid, glenoid fossa and tympanic plate dimensions. Aligned with cranial length on the second factor are temporal squamous height and petrous pyramid length. The linear non-temporal variables, foramen magnum length and breadth associate on Factor 2 with length-related variables.

This suggests the group of temporal variables on Factor 1 are primarily influenced by cranial breadth and those on Factor 2 by cranial length. However, there is considerable overlap in association between some variables in the two factors (e.g. cranial height and length and temporal squamous height have similar loading magnitudes on both factors), and the factors are by no means completely independent of one another (Fig.6.2.5.1). Factors 1 and 2 together account for 37.2% of the total variance.

From consideration of correlation coefficients, (Appendix Table A.6.2), the temporal variables on Factor 1 (dimensions of mastoid process, glenoid fossa and tympanic plate) do have higher correlation with cranial (biauricular) breadth than with cranial length or cranial height or with any temporal variable. For each of the 2 temporal variables on Factor 2, petrous length and temporal squamous height, the correlation coefficients with cranial height, length or breadth are

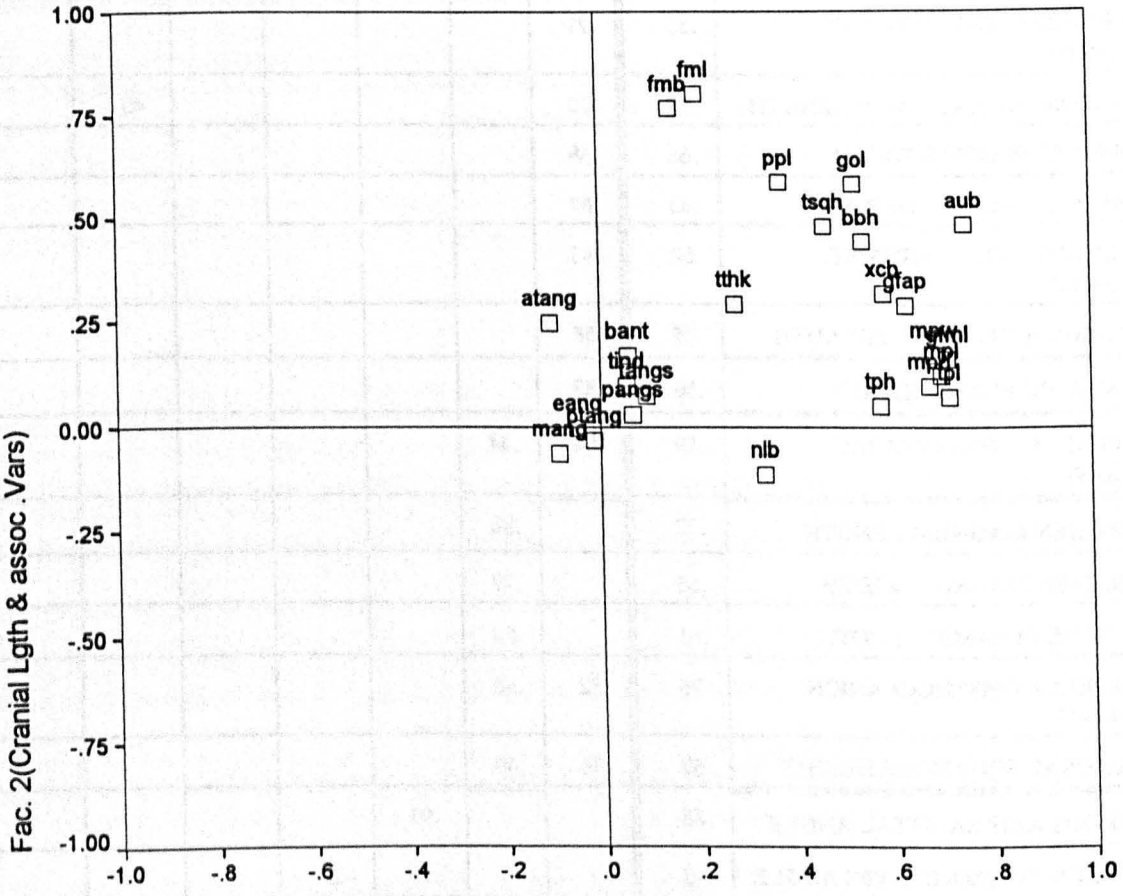
TABLE 6:5 FACTOR ANALYSIS OF TEMPORAL & NON-TEMPORAL LINEAR VARIABLES

Summary of communalities and factor loadings (> 0.4) of 18 temporal variables and 7 non-temporal linear variables for 11 population samples.

VARIABLES	COM	F1	F2	F3	F4	F5	F6	F7
BIAURICULAR BREADTH	.87	.75	.48					
TYMPANIC PLATE LENGTH	.62	.72						
GLENOID FOSSA MED./LAT. LENGTH	.55	.71						
MASTOID PROCESS AXIS LENGTH	.70	.70					.40	
MASTOID PROCESS WIDTH	.64	.68						
MASTOID PROCESS DEPTH	.63	.67						
GLENOID FOSSA ANT/POST. LENGTH	.52	.63						
MAXIMUM PARIETAL BREADTH	.65	.58						
TYMPANIC PLATE HEIGHT	.50	.57						
BREGMA-BASION CRANIAL HEIGHT	.59	.54	.44					
FORAMEN MAGNUM LENGTH	.72		.80					
FORAMEN MAGNUM WIDTH	.65		.77					
PETROUS PYRAMID LENGTH	.61		.59					
GLABELLA-OPISTHOCRANION LENGTH	.75	.52	.58					
TEMPORAL SQUAMOUS HEIGHT	.57	.46	.48					
PETROUS AXIS SAGITTAL ANGLE	.88			.91				
PETROUS-TYMPANIC AXES ANGLE	.93			.78	-.54			
NASAL WIDTH	.44			-.43				
TYMPANIC AXIS SAGITTAL ANGLE	.87				.91			
ANTERIORITY OF BASION	.63				-.71			
TYMPANIC PLATE LATERAL RIM INDENT	.67					-.77		
TYMPANIC PLATE LATERAL RIM THICKNESS	.69					.68		
TYMPANIC PLATE ANTERIOR SAGITTAL ANGLE	.55					.58		
MASTOID PROCESS AXIS ANGLE	.77						-.86	
EXT.AUD.MEATUS AXIS ANGLE	.79							.88

	TOTAL	F1	F2	F3	F4	F5	F6	F7
% VARIANCE accounted for by FACTORS	67.3	28.0	9.2	8.3	7.6	5.3	4.6	4.2

Fig.6.2.5.1 Factor 2 vs. Factor 1, Analysis 5



Overlap of variable loadings on size factors 1 & 2 show these factors are not independent. NLB & TTHK show weak positive association with F1.

approximately equal and are higher than their correlations with any temporal variables.

Nasal width associates negatively with petrous-tympanic angle and petrous angle on Factor 3, but with a low loading (-.43) and low correlations ($r=-.16$, $p<.001$, $r=-.23$, $p< .001$, respectively). This factor accounts for 9.2% of the total variance.

6.2.6. ANALYSIS 6. HOW ARE TEMPORAL VARIABLES RELATED TO NON-TEMPORAL LINEAR, ANGULAR AND SHAPE VARIABLES ?

The sixth factor analysis deals with a total of 19 temporal and 20 non-temporal variables. These variables consisted of two further cranial breadths, three cranial arcs, staphylion-hormion length, and glenoid fossa depth (a temporal dimension), together with as many of the variables from Analyses 1-5 as would yield a stable factor solution. With 8 complex variables (variables having loading >.40 on more than 1 factor), the factor matrix is not as clearly defined as in previous analyses, but the same basic temporal variable structure is present (Table 6.6).

As in Analysis 5, the first two factors relate to cranial size and account for 35.0% of the total variance. Variables measuring different aspects of overall cranial breadth principally gather on Factor 1, and those measuring overall cranial length and height on Factor 2; the 9 linear temporal variables align as they had in Analysis 5 with either Factor 1 (mastoid, glenoid fossa and tympanic plate dimensions) or Factor 2 (temporal squamous height and petrous pyramid length). Of the non-temporal variables, nasal width and staphylion-hormion length appear in the first factor, foramen magnum length and width and cranial breadths ratio in the second. As was the case in Analysis 5, there is considerable inter-dependence between the two factors; overlap of Factors 1 & 2 associations is evident in the factor plot, Fig.6.2.6.1; 6 variables had loadings >.40 in both factors (Table 6.6). Therefore, separation of cranial size-related variables into two factors gives no more than an indication as to whether a particular temporal linear variable is more influenced by cranial breadth or cranial length.

On Factor 5, Cranial breadth/length ratio and frontal arc are negatively associated with mastoid axis angle ($r=.19$,

TABLE 6:6 FACTOR ANALYSIS OF TEMPORAL AND NON-TEMPORAL LINEAR AND SHAPE-RELATED VARIABLES. Summary of communalities and factor loadings (› 0.4) of 19 temporal variables and 20 non-temporal linear and shape ratio variables for 11 population samples.

VARIABLES	COM	F1	F2	F3	F4	F5	F6
MASTOID PROCESS AXIS LENGTH	.69	.77					
MASTOID PROCESS WIDTH	.65	.71					
MASTOID PROCESS DEPTH	.62	.68					
TYMPANIC PLATE LENGTH	.61	.66					
GLENOID FOSSA MED./LAT. LENGTH	.57	.66					
BIAURICULAR BREADTH	.90	.65	.60				
GLENOID FOSSA ANT/POST. LENGTH	.58	.57					
STAPHYLION-HORMION LENGTH	.55	.56					
BIASTERION BREADTH	.67	.56	.48				
GLENOID FOSSA DEPTH	.42	.52					
TYMPANIC PLATE HEIGHT	.58	.51					
MINIMUM CRANIAL BREADTH	.51	.51	.45				
(MAXIMUM PARIETAL BREADTH)	.86	(.48)					
NASAL BREADTH	.62	.46					
FORAMEN MAGNUM LENGTH	.69		.80				
FORAMEN MAGNUM WIDTH	.59		.72				
GLABELLA-OPISTHOCRANION LENGTH	.91	.43	.65			.47	
PETROUS PYRAMID LENGTH	.60		.56				
TEMPORAL SQUAMOUS HEIGHT	.59		.55				
BREGMA-BASION CRANIAL HEIGHT	.83	.42	.54				
PARIETAL ARC	.60		.48				
S.CREST BDTH/MAX.PARIETAL BDTH.	.75		.47				
LAMBDA-OPISTHION OCCIPITAL ARC	.64	.40	.41				
LAMBDA-INION/IN.-OPISTHION RATIO	.81			-.85			
ENDINION-INION SEPARATION	.73			-.79			
OPISTHOCRANION-INION ARC	.67			-.69			
TYMPANIC PLATE SAGITTAL ANGLE	.82				.88		
ANTERIORITY OF BASION	.65				-.73		
CRANIAL BREADTH/LENGTH RATIO	.80					-.70	
MASTOID PROCESS AXIS ANGLE	.54					-.58	
FRONTAL ARC	.71		.48			.54	

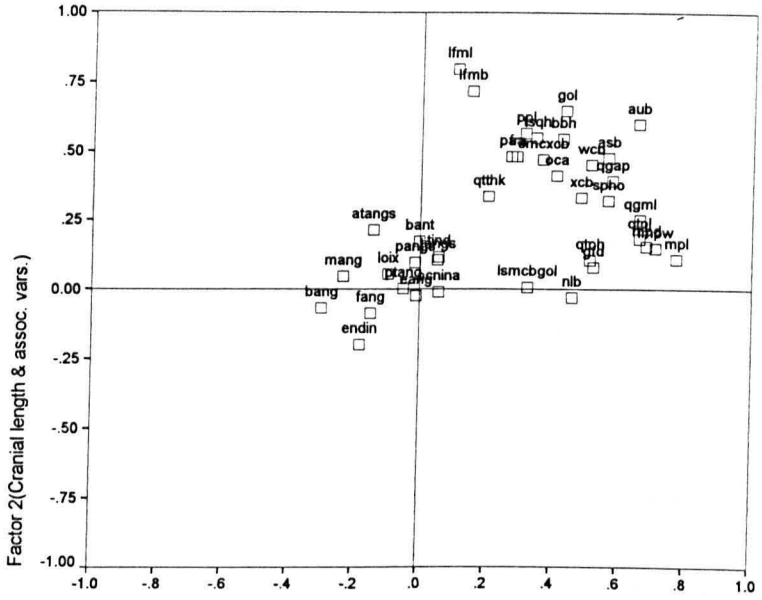
TABLE 6:6 (contd):

VARIABLES	COM	F1	F2	F3	F4	F5	F6
PETROUS PYRAMID SAGITTAL ANGLE	.89						.90
PETROUS PYR/TYMP.PLATE ANGLE	.93				-.46		.83

VARIABLES	COM	F7	F8	F9	F10
TYMPANIC PLATE LATERAL RIM THICKNESS	.72	.69			
TYMPANIC PLATE LATERAL RIM INDENT	.65	-.69			
TYMPANIC PLATE ANTERIOR SAGITTAL ANGLE	.57	.55			
BASE FLEXION ANGLE	.57		-.64		
MAXIMUM PARIETAL BREADTH	.86		.52		
(NASAL APERTURE WIDTH)	(.62		-.45)		
FORAMEN MAGNUM ANGLE	.74			.82	
(BREGMA-BASION CRANIAL HEIGHT)	(.83			.51)	
EXT.AUD.MEATUS AXIS ANGLE	.67				.80

%VARIANCE accounted for by FACTORS	TOTAL	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
	67.9	26.6	7.4	6.2	5.7	5.2	4.5	3.5	3.1	3.0	2.7

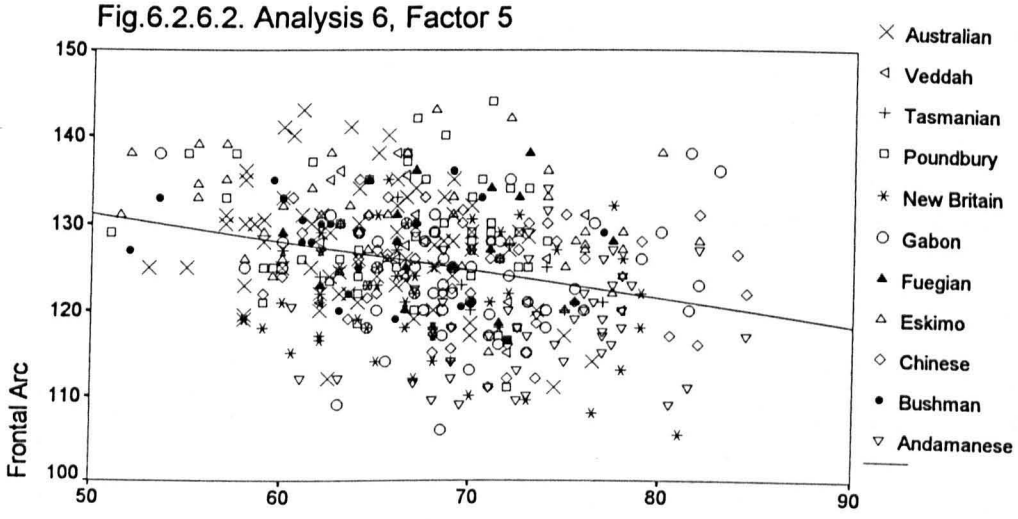
Fig.6.2.6.1 Factor 2 vs. Factor 1, Analysis 6



Factor 1(Cranial breadths & associated variables)

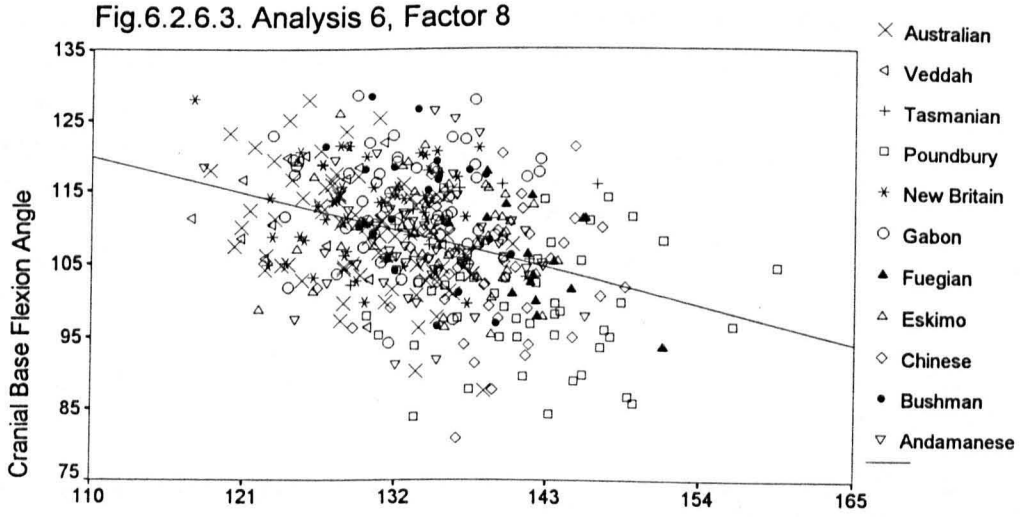
Considerable overlap of F1 variables with F2 variables shows that the two factors are not independent.

Fig.6.2.6.2. Analysis 6, Factor 5



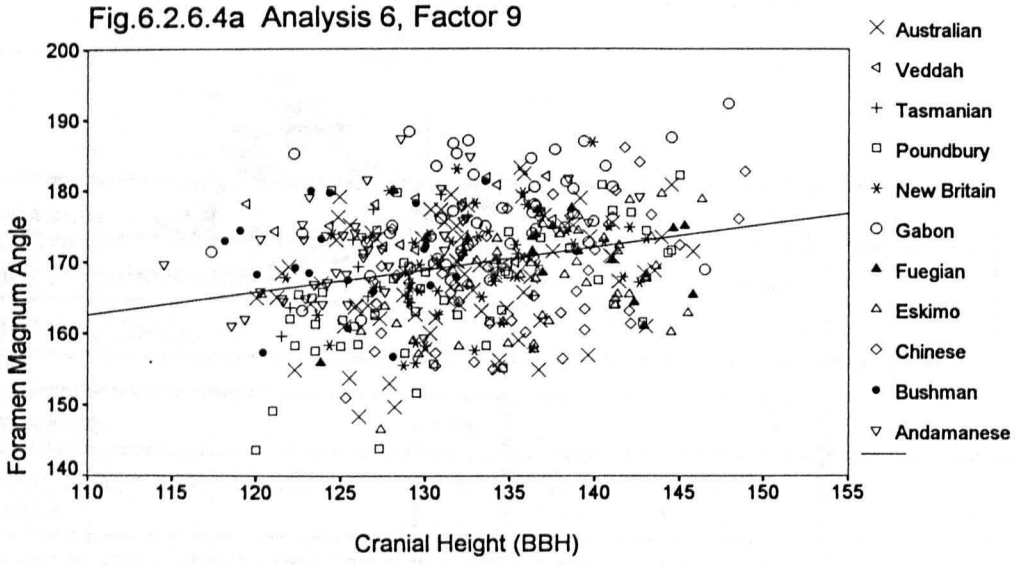
FRA = -.323 MANG + 147.3 r = - .281, p< .001

Fig.6.2.6.3. Analysis 6, Factor 8



BANG = -.466 XCB + 171.0 r = - .367, p< .001

Fig.6.2.6.4a Analysis 6, Factor 9



FANG = .317 BBH + 127.7 r = .270, p< .001

Fig.6.2.6.4b RELATIONSHIP BETWEEN THE FORAMEN MAGNUM ORIENTATION AND THE CRANIAL HEIGHT.

B=basion; BG=bregma; FH=Frankfurt Horizontal; F=foramen magnum angle; L=lambda; O=opisthion; PO=porion; S=staphylion.

B_1-BG_1 < B_2-BG_2, F_1 < F_2

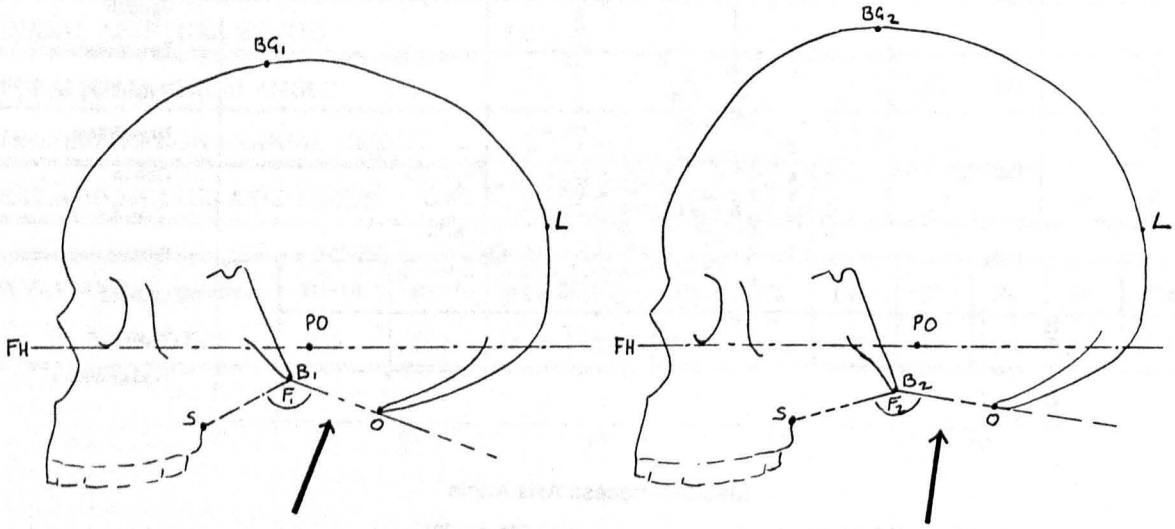
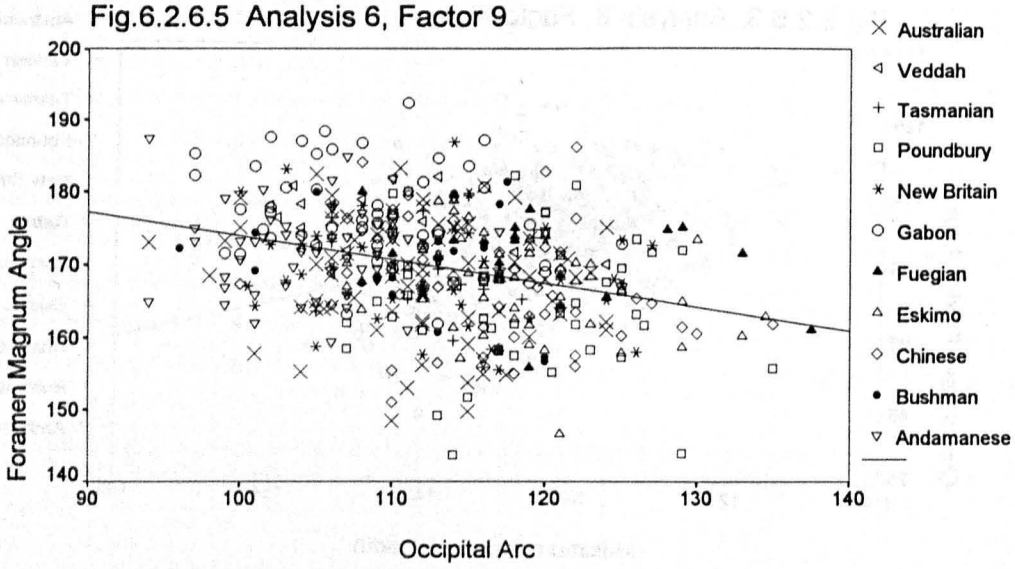


Fig.6.2.6.5 Analysis 6, Factor 9



FANG = -.327 OCA + 206.6 r = -.324, p< .001

p<.001, r=-.28, p<.001 respectively). This implies crania which are short relative to their breadth and have short frontal arcs tend to have mastoids with axes inclined towards the vertical (Fig.6.2.6.2). This factor accounts for 5.2% of the total variance.

As in analysis 3, there was no indication of any temporal variables being related to base flexion angle. But on Factor 8 the base angle is negatively associated with maximum parietal breadth, suggesting that the most flexed crania also tend to be broadest across the parietals. (Poundbury, Chinese and Fuegian have the largest absolute means for maximum parietal breadth, and smallest absolute means for base angle (Appendix Table A.5.1) Certainly base angle is more highly correlated with maximum parietal breadth than with any other variable (r=-.37, p<.001), (Fig.6.2.6.3).

Nasal width shows very weak association on both this factor and Factor 1, but as indicated by its lack of significant correlation with base angle (r = .065, p >.01) or parietal breadth (r = .003, p>.01), the Factor 8 association is no more than random. Only 3.1% of the total variance is accounted for by Factor 8.

In Analysis 3, the orientation of foramen magnum and mastoid process axis angle were linked. In this analysis, foramen magnum angle positively associates with cranial height on Factor 9, suggesting a connection between low crania and foramen magna which are rotated forward i.e. have a small foramen magnum angle (r = .27, p <.001), (Figs.6.2.6.4a & b). This result coincides with that of Bjork in examining the inter-dependence of cranial base shape variation and brain case development in modern humans between the ages of 12-20 years; he found that the forward deflection of the foramen magnum (i.e. reduced foramen magnum angle as defined in this study) is accompanied by a reduced height of the brain case (Bjork 1955:215,126)

The highest correlation of foramen magnum angle is with occipital arc (r = .32, p <.001), suggesting crania with long occipitals tend to have forward angled foramen magnum (Fig.6.2.6.5). Both these links are consistent with orientation of the foramen magnum being influenced at least in part by the downwards/forwards rotation of the brain. Factor 9 accounted for only 3.0% of the total variance.

6.2.7. SUMMARY

HOW ARE TEMPORAL VARIABLES RELATED TO EACH OTHER AND TO OTHER VARIABLES?

Factor models obtained from the 6 analyses consisted of 6-10 factors which together accounted for approximately two thirds (64.0%-67.9%) of the total variance. Different combinations of temporal variables with non-temporal variables from one analysis to another yielded some different relationships, but all analyses showed a similar general pattern between the temporal variables.

All but 3 temporal linear variables are related to overall cranial size through their association with cranial size dimension variables on the first one or two factors. However, when temporal variables alone are considered, the nine size-related temporal measurements account for only 24.2% of the total variance, leaving over three quarters to be explained by factors other than size. In particular, mastoid process is size-related but according to the relevant communality values (Table 1), only 44% of its depth, 36% of its width and 59% of its length are accounted for by its association with cranial size.

Some linear temporal variables, (mastoid process length, width and depth, glenoid fossa depth, glenoid fossa anterior-posterior and medial-lateral lengths, tympanic plate length and height), are more strongly associated with cranial breadth; whereas petrous pyramid length and temporal squamous height seem to correspond as much to cranial length and height as to cranial breadth. Petrous pyramid length also has strong association with the non-temporal variable, foramen magnum length.

The remaining temporal variables are virtually independent of those size-related linear temporal measurements and from overall cranial size. Except for anteriority of basion and tympanic lateral rim thickness and indent, the temporal variables not related to cranial size are all angular measurements and reveal a number of probable relationships among themselves and with some non-temporal variables.

Increase in tympanic-petrous angle corresponds to an increase in petrous pyramid sagittal angle and decrease in tympanic plate sagittal angle. But tympanic plate orientation and petrous pyramid orientation show some degree of independence, being found in different factors. The tympanic plate angle is more closely related to the position of foramen magnum; the more anterior the position of the foramen magnum, the more sagitally oriented the tympanic axis.

Associations in other factors imply that a tympanic plate with a thick lateral rim tends to have a less indented rim, a more coronally oriented anterior side and is associated with crania which are narrow relative to their length and have low maximum cranial breadth.

Mastoid axis orientation shows independence from other temporal variables apart from a weak negative link with mastoid length. Mastoid axis angle is positively associated with 2 non-temporal variables, orientation of the foramen magnum and cranial breadth to length ratio. Mastoid processes which have axes angled away from the vertical tend to be relatively long, and come from crania which are long compared to their breadth and which have foramen magnum rotated forward.

Apart from a weak negative association with petrous angle and petrous-tympanic angle, nasal width and nasal width/height ratio are comparatively independent of all other variables in the analyses, temporal or non-temporal.

Temporal variables appear to be independent of both base flexion and the group of occipital measurements (endinion-inion separation, opisthocranion-inion separation and occipital chord ratio). These three occipital variables proved to be also independent of overall cranial size. Base angle has a specific, negative link with biparietal breadth, flexed bases being associated with crania with broad parietals.

6.3 RESULTS AND DISCUSSION II: COMPARISON OF AUSTRALIAN TEMPORAL VARIABLE RELATIONSHIPS TO THOSE OF OTHER GROUPS

6.3.1 INTRODUCTION

Do Australian crania differ noticeably from crania of other modern population groups in any of the components resulting from factor analysis?

As a means of comparison, factor mean scores of each of the eleven population groups were plotted (Figs.6.3.1-6.3.9). Since similar plots resulted from equivalent factors (components) in all analyses only one plot is given for each component. Because of possible bias due to small sample size, generalisations drawn from the results when applied to populations represented by the 4 smaller samples (Bushman (21), Fuegian (16), Tasmanian (11) and Veddah (18)) should be treated with caution.

Several components involving different variable associations are considered in the comparison.

6.3.2.1 CRANIAL SIZE COMPONENT.

(Factor 1 in Analyses 1-4, Factors 1 & 2 in Analyses 5 & 6). What measurements or group of measurements should be used to determine if a cranium is "large" or "small"?

(i) In analyses 2 and 3 only the first factor is related to overall cranial size and consists of a positive association of cranial length, height and breadth measurements, (GOL, BBH, AUB), together with most linear temporal measurements. From the resulting distribution of factor mean scores for 11 groups (Fig.6.3.1a), the "largest" crania belong to Fuegian, Chinese, Poundbury, and Eskimo; the Fuegian mean score is extremely large. Andamanese and Bushman have the "smallest" crania, and in the middle of the distribution are Australian, New Britain, Gabon, Tasmanian and Veddah.

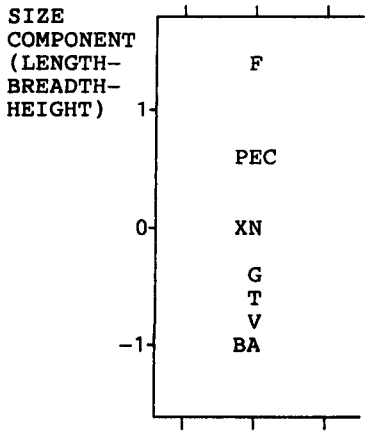
(ii) In Analyses 5 and 6, both Factor 1 and Factor 2 are related to overall cranial size, one consisting of cranial breadths and mastoid, glenoid fossa and tympanic size measurements, the other of cranial lengths, petrous length and

temporal squamous height. There are a number of notable differences in the relative arrangement of mean scores for the two factors, (Fig.6.3.1b). Based on the factor comprising cranial length and associated variables, the mean score for Eskimos far exceeds that of all other groups, whereas based on the factor comprising cranial breadth variables, the Eskimo mean is in the low medium range only. This is consistent with Eskimo crania being very long but narrow in relation to length. Based on the cranial breadth size factor Veddah, Bushman and Andamanese are equally the smallest, but with cranial length factor the criterion, Andamanese are separated as significantly smaller than all others. Australian crania mean scores are intermediate for both Factors 1 and 2.

(iii) In Analysis 1 and 4, in which there are no variables directly measuring overall cranial dimensions, the first factor comprises 9 temporal linear variables only. This yields a similar pattern of mean score distribution as the cranial breadth factor except that the Tasmanian score is particularly low, suggesting generally small temporal features (Fig.6.3.1c). The implication for Eskimos is that for the length of their crania they tend to have small temporal features. Based on size-related temporal variables, Australian and New Britain crania again have intermediate factor mean scores.

The size-related factors, which account for 24.2%- 28.7% of the total variance, do not distinguish Australian crania from other modern groups. Rather, all size-related factors categorise Australian and New Britain crania as intermediate in overall cranial size.

Fig.6.3.1a OVERALL CRANIAL SIZE (1)



Figs.6.3.1 - 6.3.9 ABBREVIATIONS

A = Andamanese	E = Eskimo
B = Bushman	F = Fuegian
C = Chinese	G = Gabon
N = New Britain	P = Poundbury
T = Tasmanian	V = Veddah
X = Australian	

Distribution of group mean scores from Factor 1 Analysis 3, comprising overall cranial length, breadth, height and related temporal variables.

Fig.6.3.1b OVERALL CRANIAL SIZE (2)

Distribution of group mean scores from Factors 1 and 2 Analysis 6. Factor 1 consists of cranial breadths and associated variables; Factor 2 consists of cranial length and associated variables.

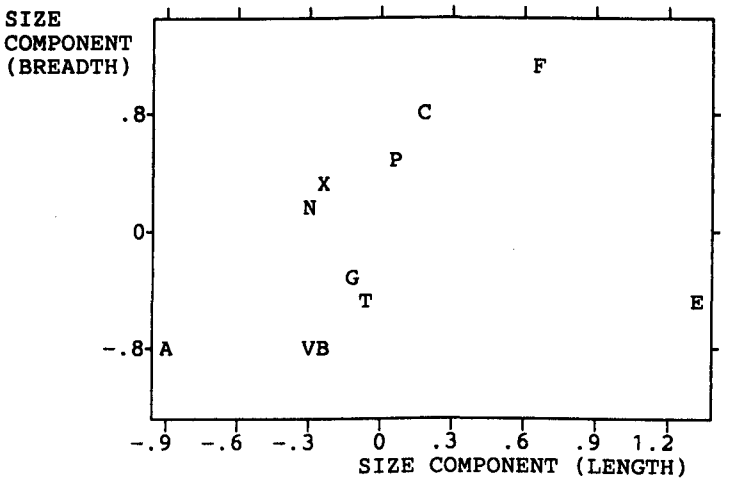


Fig.6.3.1c TEMPORAL SIZE.

Distribution of group mean scores from Factor 1 Analysis 4, which consists of variables measuring linear dimensions of the mastoid process, petrous pyramid, tympanic plate, glenoid fossa, temporal squamous.

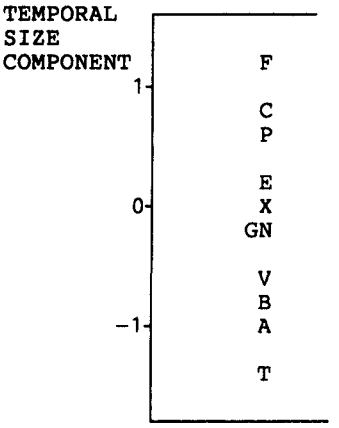
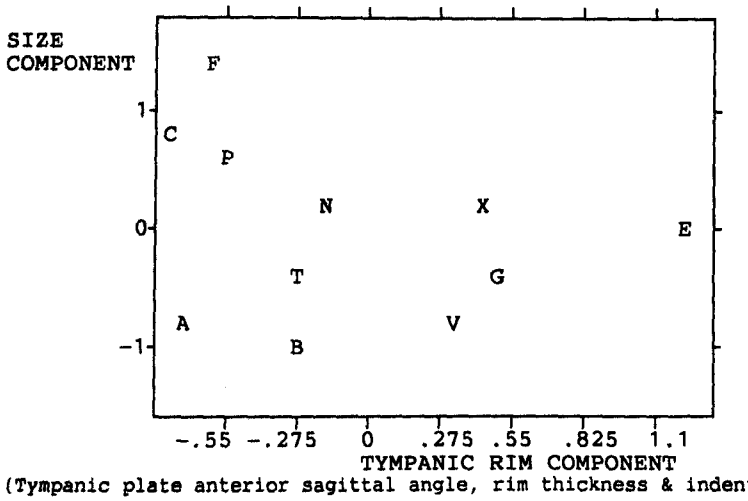
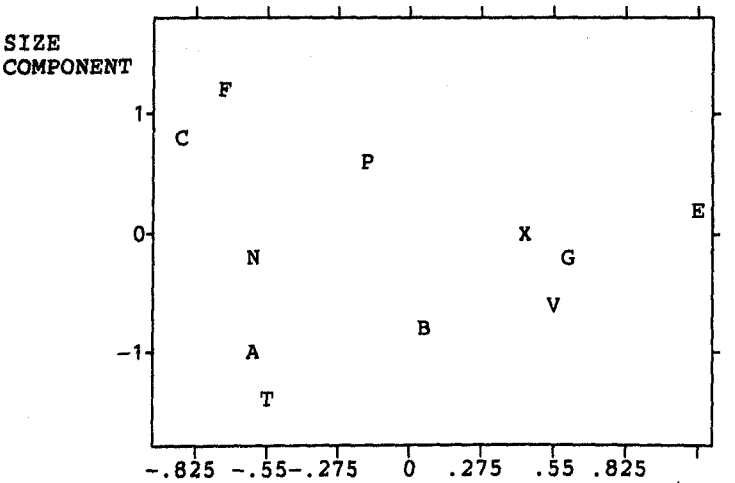


Fig.6.3.2a TYMPANIC RIM COMPONENT.
Plot of group mean scores from Analysis 5, Factors 1 with Factor 5. Factor 5 consists of the tympanic plate lateral rim thickness and indent, and anterior sagittal angle .



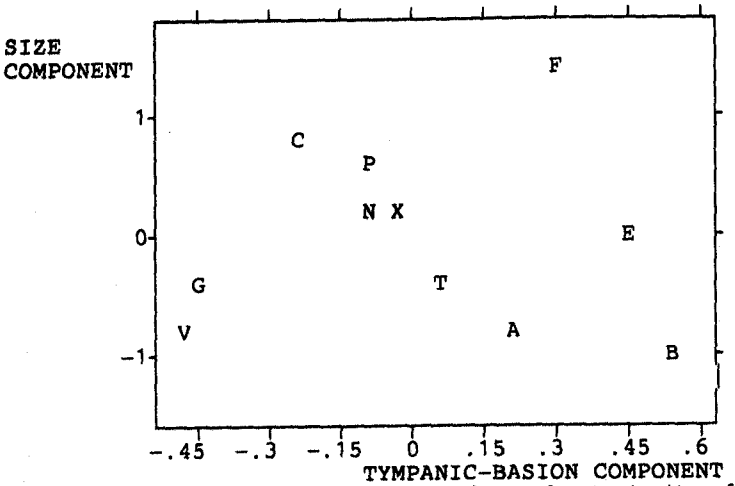
(Tympanic plate anterior sagittal angle, rim thickness & indent)

Fig.6.3.2b TYMPANIC RIM COMPONENT (including CRANIAL BREADTH/LENGTH).Plot of group mean scores from Analysis 4, Factors 1 with Factor 4. Factor 4 consists of the tympanic plate lateral rim thickness and indent, tympanic anterior sagittal angle and cranial breadth/length ratio.



(Tympanic ant.sagittal angle, rim thickness & indent and cranial breadth/length ratio).

Fig.6.3.3 TYMPANIC-BASION COMPONENT
Plot of group mean scores from Analysis 5, Factors 1 with Factor 4. Factor 4 consists of the tympanic plate axis sagittal angle and anteriority of basion relative to the bitympanic line.



(Tympanic plate axis sagittal angle and anteriority of basion)

6.3.2.2 TYMPANIC RIM COMPONENT: This factor comprises tympanic plate lateral rim thickness and indent and tympanic anterior sagittal angle. (Factors 4,3,2,4,5,7 in Analyses 1-6 respectively.)

From Analysis 5, the size-related first factor is plotted with the Tympanic Rim Component on Factor 5 (Fig.6.3.2a). The Eskimo's striking separation from all other groups on the basis of this 3 variable complex highlights the extreme robustness of the Eskimo tympanic plate in its pronounced rim thickness. Australian, Gabon and Veddah groups show the same tendency, though not nearly as extreme, while the Chinese and Andamanese exhibit a combination of the thinnest, most indented tympanic plate with its anterior side most sagitally inclined. Compared to Australians, the lower factor mean scores of New Britain and Tasmanian crania reflect their noticeably more gracile tympanic plate. Surprisingly, with one of the lowest mean scores for this factor, Fuegians were markedly different from Eskimos.

In Analysis 4, the 3 tympanic variables were joined by the cranial breadth to length ratio which had negative association with tympanic plate thickness and anterior sagittal angle (Fig.6.3.2b). This combination did not greatly affect the order of factor mean scores but did enhance the separation of the thick rimmed Australian, Gabon, Veddah and Eskimos from all other groups, including New Britain and Tasmanian, and emphasised the position at the other end of the distribution of the broad Chinese crania of thin tympanic plate rim combination.

The tympanic rim factor, which accounts for 8.8% of the total variance in Analysis 1 for temporal variables only, singles out Eskimos from other modern groups.

6.3.2.3. TYMPANIC-BASION COMPONENT: This factor comprises tympanic axis sagittal angle and the position of basion (and foramen magnum) relative to the bitympanic line. (Factors 2,2,3,3,4,4 in Analyses 1-6 respectively.)

Australian, Tasmanian and New Britain mean scores for this factor are in the middle range of the distribution. (Fig.6.3.3; Factor 1 from Analysis 5 is plotted with Factor 4.) Bushman, then Eskimos and Fuegians, show the most coronally oriented tympanic axis and a posteriorly placed

basion. At the other extreme of the distribution are Gabon and Veddah, having the most sagitally inclined tympanic axes. This places the two African groups at opposite ends of the distribution, suggesting this component may distinguish Bushman from Gabon.

The Tympanic-basion component accounts for 12.0% of the total variance in Analysis 1 for temporal variables only. Australians are unremarkable in the relationship.

6.3.2.4 PETROUS ANGLE COMPONENT. This factor comprises petrous axis sagittal angle and petrous-tympanic angle. (Factors 3,4,4,5,3,6 in Analyses 1-6 respectively).

As depicted in the plot of Factor 1 with Factor 4 from Analysis 2 (Fig.6.3.4a), this component of petrous angle and petrous-tympanic angle aligns Australians with the two African groups, Gabon and Bushman: factor mean scores indicate these 3 groups have noticeably more acute petrous axis sagittal angle and petrous-tympanic angle than other groups. The Tasmanian, then the Eskimo have the most coronally oriented petrous axis and a large petrous-tympanic angle. The New Britain factor mean score is in the medium range with most other groups.

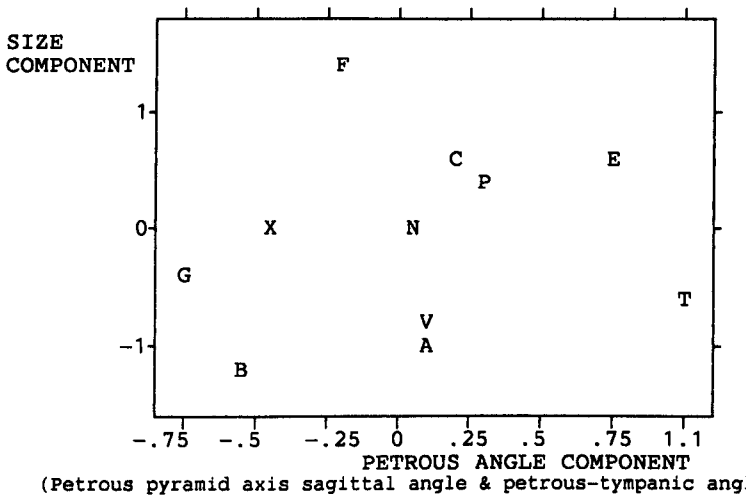
The petrous and petrous-tympanic angles are negatively associated with nasal width/height ratio (Analysis 4) and nasal width (Analysis 5). According to absolute means, nasal aperture tends to be especially narrow for Eskimos and wide for Tasmanians, so addition of nasal dimensions to the factor emphasises the extreme position of Eskimos but reduces the factor mean score of Tasmanians to intermediate (Fig.6.3.4b). For other groups the distribution of scores is unchanged.

This component accounts for 10.5% of the total variance in Analysis 1 for temporal variables only. It does not separate Australians from all other modern groups, but it does align them with the African groups and distinguish them from the Tasmanians.

That the orientation of the petrous axis is largely independent of that of the tympanic axis is shown in the plot of Analysis 2 Factor 2 (the tympanic-basion component) with Factor 4 (the petrous angle component) (Fig.6.3.4c). The correlation coefficient for the 2 variables ($r=.200$, $p<.001$) implies a very weak positive association.

Fig.6.3.4a PETROUS ANGLE COMPONENT

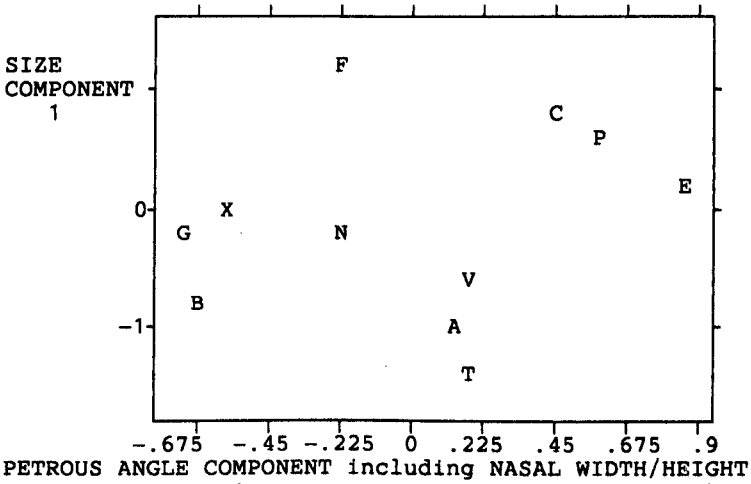
Plot of group mean scores from Analysis 2, Factor 1 with Factor 3. Factor 3 consists of the petrous pyramid axis sagittal angle and petrous-tympanic angle.



(Petrous pyramid axis sagittal angle & petrous-tympanic angle)

Fig.6.3.4b PETROUS ANGLE COMPONENT (including NASAL WIDTH/HEIGHT RATIO)

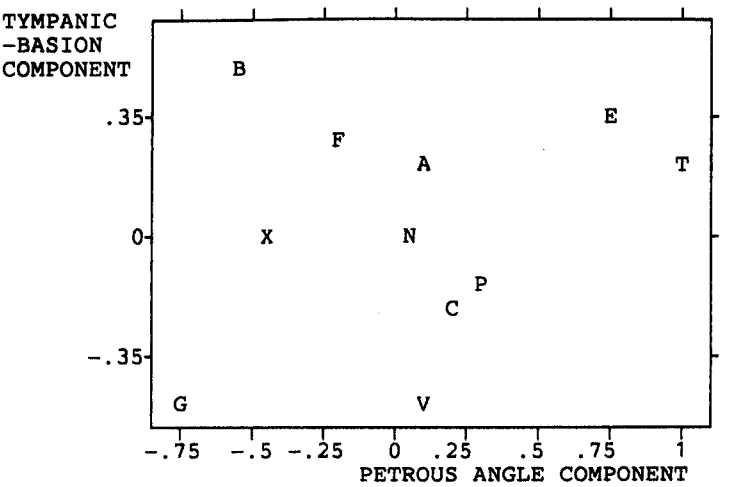
Plot of group mean scores from Analysis 4, Factors 1 with Factor 5. Factor 3 consists of the petrous pyramid sagittal angle, petrous-tympanic angle and nasal width /height ratio.



(Petrous sag.angle, petrous-tympanic angle & nasal width/height ratio)

Fig.6.3.4c TYMPANIC-BASION & PETROUS ANGLE COMPONENTS

Plot of group mean scores from Analysis 2, Factors 2 with Factor 4. Factor 2 consists of the tympanic plate axis sagittal angle and anteriority of basion, and Factor 4 comprises petrous pyramid axis sagittal angle and petrous-tympanic angle.



(Petrous pyramid axis sagittal angle and petrous-tympanic angle)

6.3.2.5 MASTOID ANGLE COMPONENT

This factor comprises principally the mastoid process axis angle. (Factors 5,5,5,7,6,5 in Analyses 1-6 respectively.)

In Analyses 1,2,4, and 5, the Australians are separated from all other groups on the basis of the mastoid process angle, in weak negative association with mastoid process length. Australians have a considerably lower factor mean score for this component than other groups (Fig.6.3.5). This suggests that a distinguishing feature for Australian crania is a combination of a mastoid process axis which tends to be long and noticeably inclined away from the vertical. (The Bushman absolute mean value for mastoid angle is as small as that of Australians; Poundbury and Fuegian have larger mastoid process length absolute means than that of Australians.)

In Analysis 6, where cranial breadth/length ratio and frontal arc are seen to associate with mastoid angle, and in Analysis 3 where foramen magnum angle is seen to associate with mastoid angle, Australians still have the lowest mean score but there is no distinct separation from other groups. Andamanese and Chinese have the most vertically inclined mastoid process. New Britain and Tasmanian scores are in the middle of the distribution.

The mastoid angle component accounts for merely 6.2% of the total variance in Analysis 1 for temporal variables only.

The main function of the mastoid process is as a surface of attachment for 3 muscles (sterno-mastoid, splenius capitis and trachelo-mastoid) concerned with different aspects of the balancing, turning and flexion of the head. The orientation of the mastoid process would be governed by the combined effect of the orientation of the 3 muscles, which in turn may depend on such factors as the degree of prognathism, the angle at which the head is held, the length of the neck, and the weight and placement of superstructures such as occipital tori, supraorbital arches. The weak positive correlation found in Analysis 3 between the mastoid angle and the foramen magnum angle supports the existence of a link between mastoid orientation and the angle at which the head is held.

Since many Australian crania exhibit substantial lower face prognathism (Howells 1989:14), it is a probable link with the acute mastoid angle in Australians, but suitable measurements to assess such prognathism were not included in this study.

Fig.6.3.5 MASTOID ANGLE COMPONENT

Plot of mean scores from Analysis 5, Factor 1 with Factor 6. Factor 6 consists of the mastoid process axis angle and a weak negative contribution from the mastoid length.

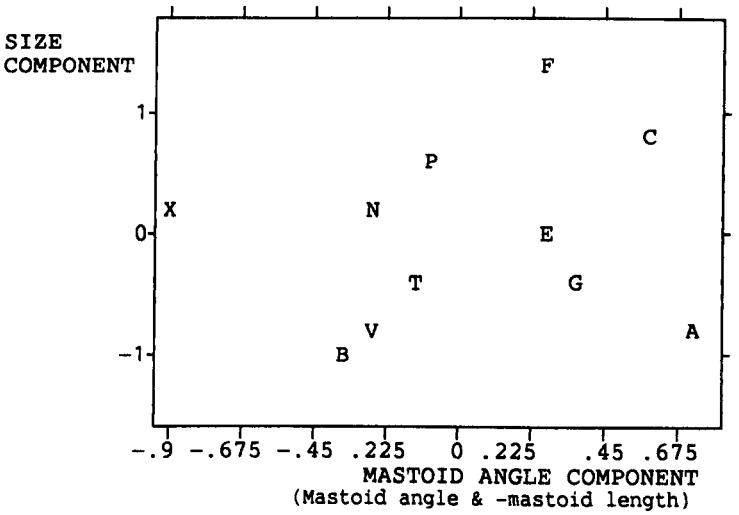


Fig.6.3.6. EXTERNAL AUDITORY MEATUS ANGLE COMPONENT

Plot of group mean scores from Analysis 5, Factors 1 with Factor 7. The latter factor consisted of the external auditory meatus angle.

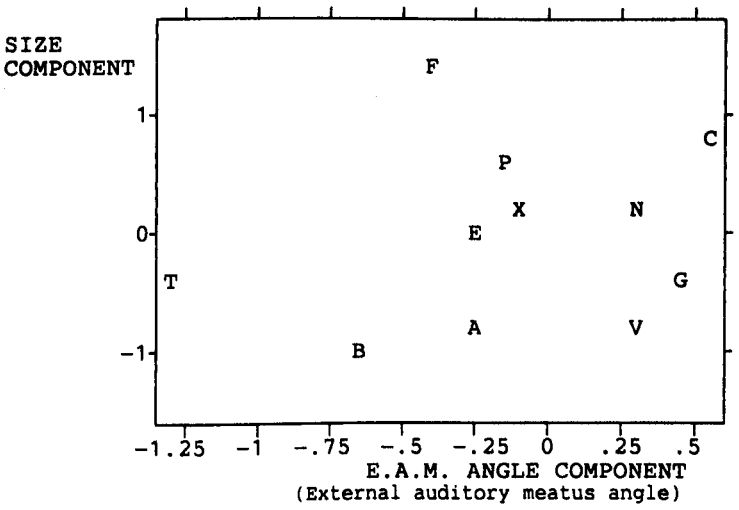


Fig.6.3.7 FORAMEN MAGNUM ANGLE COMPONENT

Plot of group mean scores from Analysis 6, Factors 1 with Factor 9. Factor 9 consists of foramen magnum orientation (sphenion basion-opisthion angle) with a small contribution from cranial basion-bregma height.

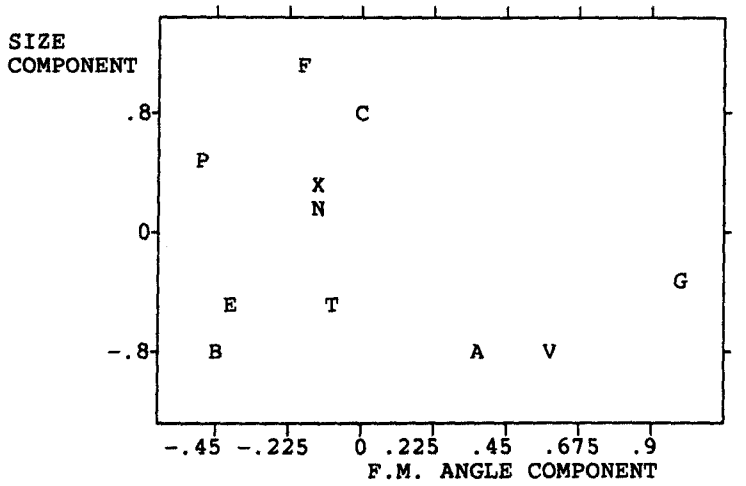


Fig.6.3.8 FLEXION-PARIETAL BREADTH COMPONENT

Plot of group mean scores from Analysis 6, Factors 1 with Factor 8. Factor 8 comprises base flexion (sphenion-hormion-basion angle) with a small negative contribution from maximum parietal breadth.

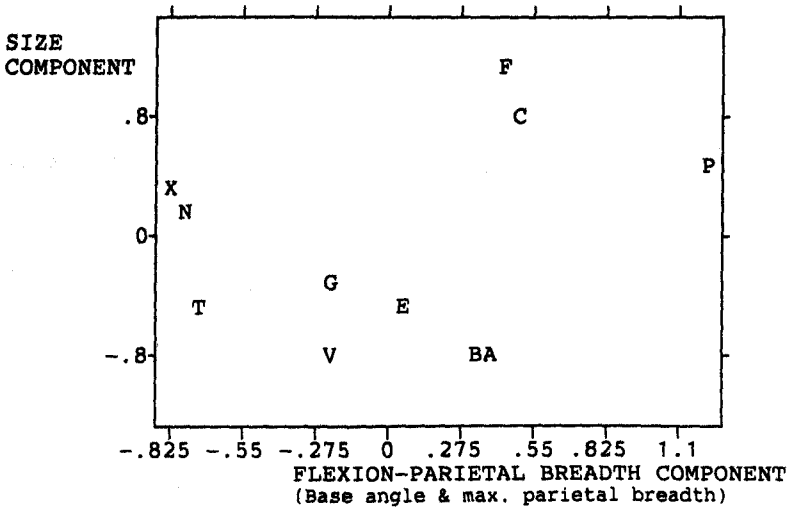
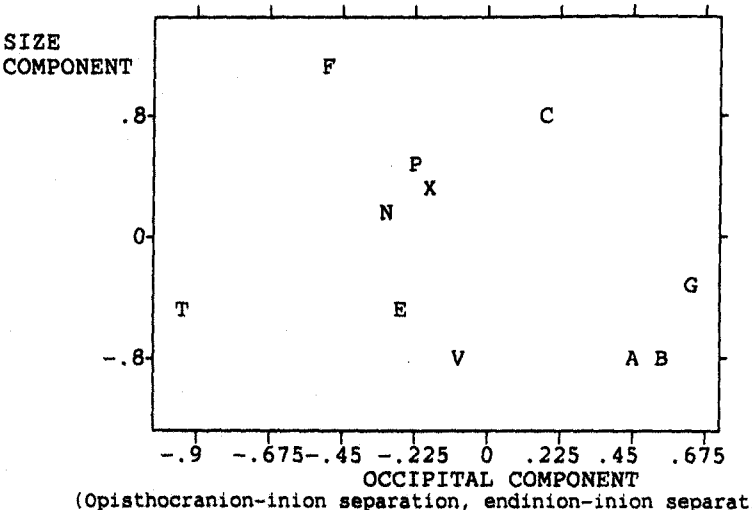


Fig.6.3.9 OCCIPITAL VARIABLE COMPLEX

Plot of group mean scores from Analysis 6, Factors 1 with Factor 3. The occipital variables comprising Factor 3 are endinion-inion separation, lambda-inion/inion-opisthion chord ratio & opisthocranion-inion separation.



6.3.2.6 E.A.M. ANGLE COMPONENT. This factor comprises principally the external auditory meatus axis angle. (Factors 6,6,6,8,7,10 in Analyses 1-6 respectively.)

In all analyses, this single variable factor accounts for the least variance of all extracted factors; in Analysis 1 for temporal variables only it accounts for merely 5.9% of the total variance. In every analysis the Tasmanian factor mean score is particularly small, suggesting that Tasmanians have the most acutely inclined external auditory meatus axis. (Fig.6.3.6; Factor 1 from Analysis 5 is plotted with Factor 7.) But the absolute mean value of Bushman for this variable is less than that of Tasmanian, so the discrepancy must be explained by the contribution of variables with loadings <.40 on this E.A.M. component. Chinese and Gabon, with consistently largest mean scores, show the opposite trend; they have the most vertical external auditory meatus axis. The Australian factor mean score is intermediate in the range.

6.3.2.7 3 NON-TEMPORAL VARIABLE FACTORS.

(i) F.M. ANGLE COMPONENT: Foramen magnum angle was included in two analyses, appearing in positive association with mastoid axis angle on Factors 5 in Analyses 3 and with cranial height on Factor 9 in Analysis 6. The latter combination separates Gabon, Andamanese and Veddah, which have largest foramen magnum angles, from the other groups (Fig.6.3.7), though the factor accounts for only 3.0% of the total variance. Australian, Tasmanian and New Britain mean scores are intermediate in the distribution.

(ii) FLEXION/PARIETAL BREADTH COMPONENT: The base flexion angle shows no association with temporal variables but in analysis 6 it is negatively linked with maximum parietal breadth on Factor 8 (Fig.6.3.8). The factor mean scores reflect the fact that Poundbury crania are extremely broad across the parietals and have the most flexed base, while Australians, New Britain and Tasmanian are at the other extreme with a combination of narrow parietals and flat base. However, the Australian base angle absolute mean value is no more than intermediate and Veddah have a smaller maximum parietal breadth absolute mean.

This factor seems to separate Australo-Melanesians from other groups, but it accounts for only 3.1% of the variance.

(iii) OCCIPITAL COMPONENT: Factor 2, Analysis 4 and Factor 3, Analysis 6 each comprise 3 occipital variables, (inion-endinion separation, opisthocranion-inion separation and lambda-inion/inion-opisthion chord ratio). The distribution of group mean scores for this factor (Fig.6.3.9) show that the Australian and New Britain mean scores are again in the centre range. Tasmanians are at one extreme with a particulary low score and at the other are the Andamanese and two African groups. To explain the distribution, the absolute mean values of all 3 occipital variables in the component need to be considered. Tasmanians have the smallest absolute mean value for both inion-opisthocranion separation and lambda-inion/inion-opisthion chord ratio (large inion-opisthion chord and smallest inion-opisthion chord); their endinion-inion separation absolute mean value is also small. Mainly because of their particularly small inion-opisthion chord, Bushman and Andamanese have the largest absolute mean values for lambda-inion/inion-opisthion chord ratio and separation of endinion above endinion. Although Gabon is grouped with Bushman and Andamanese by this component, there is a different reason for its equally high factor score. Gabon has a particularly large absolute mean value for opisthocranion-inion separation; its values for the other 2 occipital variables in the component are no more than intermediate.

This occipital factor accounts for 6.2% and 9.6% of the total variance in Analyses 4 and 6 respectively. It does not distinguish the Australians, but groups which exhibit prominent parietal bosses and no occipital tori score high on this component while groups which have a high incidence of prominent occipital tori tend to have low scores.

6.3.3 SUMMARY

HOW DO AUSTRALIAN CRANIA DIFFER FROM OTHER MODERN HUMAN CRANIA, PARTICULARLY IN TEMPORAL FEATURES ?

The following conclusions have been reached on the basis of comparison of group factor mean scores resulting from the 6 factor analyses and in reference to group absolute mean values for the variables associated with the different factors.

6.3.3.1 DO ANY FACTOR COMPONENTS DISTINGUISH AUSTRALIAN CRANIA FROM ALL OTHER GROUPS?

Mastoid Angle Component. Only the factor involving mastoid process axis orientation (coupled with a small negative contribution from mastoid process length) noticeably separates the Australians from all other groups. The Australian factor mean score is considerably less than that of all other groups indicating Australian crania have a distinctive combination of a long mastoid process axis inclined away from the vertical. However, the Mastoid Angle Component accounts for only a small amount of the variance (6.2% in Analysis 1). The inclination of the mastoid process is likely to be associated with the angle at which the head is held and possibly the degree of lower face prognathism.

Petrous Angle Component. Though this factor does not distinguish Australians from all other groups, it does place them with the 2 African groups. According to the distribution of factor mean scores and the absolute mean values, Australians, Bushman and Gabon have the most acute petrous sagittal angles and petrous-tympanic angles.

Tympanic Rim Component. On the basis of this factor consisting of tympanic plate rim thickness and indent and orientation of the anterior side of the tympanic plate, Australians are aligned with the Eskimos, Gabon and Veddah as one of the 4 groups with
most robust tympanic plate. For Australians, this is because the tympanic rim is thick and protruding; the angle of the tympanic anterior side is not remarkable for Australians. However, only the Eskimos are separated from all others groups by this factor; the thickness of the Eskimo tympanic rim and

the degree of coronal orientation of the tympanic anterior side are outstanding.

Flexion-Parietal Breadth Component. For this non-temporal factor comprising cranial base flexion and maximum parietal breadth, the relatively low mean scores of the Australian, New Britain and Tasmanian groups effectively separate Australo-Melanesians from the other groups, supposedly on the basis of a combination of flat base and narrow parietals. However, this is somewhat misleading, since the absolute mean values show that Australian crania do not have a particularly flat base, and although they are very narrow across the parietals, Veddah have an even smaller maximum parietal breadth. The other variables on the component which have loadings <.40 must add an important combined influence to effect the separation of the Australian, New Britain and Tasmanian groups from others on the basis of this component.

Size Component. From the factor score means, Australians are intermediate in overall cranial size whether based on a size component involving cranial breadth, length and height dimensions (Analyses 2 & 3), or a size component related to cranial breadth (Analyses 5 & 6), or one related to mainly cranial length (Analyses 5 & 6). Australians are also intermediate when the size component consists of only size-related temporal variables (mastoid process, petrous pyramid, tympanic plate, glenoid fossa and temporal squamous linear dimensions) (Analyses 1 & 4).

The following components also fail to separate the Australians. In each case, the Australian factor mean score is in the intermediate range in all analyses where the factor appears:

Tympanic-Basion Component. The combination of tympanic axis orientation and foramen magnum/basion position (Analyses 1-6);

F.M. Angle Component. The combination of foramen magnum orientation and cranial height (Analysis 6);

E.A.M. Component. The external auditory meatus axis angle (Analyses 1-6);

Occipital Component. The combination of the 3 occipital variables, endinion-inion separation, lambda-inion/inion-opisthion ratio and opisthocranion-inion separation (Analyses 5 & 6).

6.3.3.2 DO ANY FACTOR COMPONENTS DISTINGUISH AUSTRALIAN CRANIA FROM TASMANIAN AND NEW BRITAIN CRANIA?

On the basis of Tympanic Rim and Mastoid Angle Components, Australian crania differed noticeably from both NEW BRITAIN and TASMANIAN crania. Australians have a more acutely inclined mastoid angle and a thicker, more protruding tympanic plate lateral rim. However, they differ little in orientation of the anterior side of the tympanic plate, all having intermediate absolute means for this variable .

Australians differed noticeably from TASMANIANS on the basis of a further 4 factors.

(i) Size Component. Australians have considerably larger temporal features in general (e.g. Tasmanians have the shortest, narrowest mastoid process of all groups).

(ii) Petrous Angle Component. The Australian petrous-tympanic and petrous sagittal angles are among the most acute, whereas Tasmanians have a large petrous-tympanic angle and the most coronally inclined petrous pyramid.

(iii) Occipital Component. Tasmanians have the lowest mean score on this factor because of their very small occipital separations and index. The Australian score is intermediate.

(iv) E.A.M. Component. Tasmanians have a particularly low factor mean score. Australian external auditory meatus is more vertically oriented.

The last 2 factors could distinguish Tasmanians from all other groups, though the scores may not be so extreme if the Tasmanian sample had been larger.

6.3.3.3 DO THE FACTOR COMPONENTS DISTINGUISH ANY OTHER MODERN GROUP(S) FROM ALL OTHER GROUPS?

ESKIMOS Two factors on which they have particularly high mean scores can separate Eskimos from other groups.

The Tympanic Rim Component distinguishes Eskimos because their tympanic plate has an exceptionally thick lateral rim and the most coronally oriented anterior side.

Though not a factor confined to temporal variables only, the Size Component based on cranial length also singles Eskimos out because, as absolute mean values confirm, they have the longest cranium and foramen magnum, a long petrous

pyramid and the highest temporal squamous.

With Bushman, Eskimos have the largest factor mean scores for the Tympanic-Basion Component. Consistent with this and according to absolute mean values, Eskimos have the most coronally oriented tympanic plate axis and a foramen magnum centre which is posteriorly placed. The apparent inconsistency that Eskimos also have the most anteriorly rather than posteriorly placed basion is explained in terms of their exceptionally long foramen magnum. This suggests that the orientation of the tympanic axis corresponds to the position of the whole foramen magnum rather than to the position of basion.

With Tasmanians, Eskimo have the largest factor mean score for the Petrous Angle Component. This corresponds to the Eskimo petrous pyramid axis being the most coronally oriented; however, the petrous-tympanic angle of Eskimos is no more than intermediate in magnitude.

With Poundbury and Bushman, Eskimo have the smallest F.M. Angle Component mean score, reflecting the fact that the foramen magna of those groups are relatively forward rotated.

FUEGIAN crania are outstandingly large in overall cranial size and general temporal feature size according to the factor mean scores on the Size Component in all analyses; the scores may not be so extreme for a larger Fuegian sample. Fuegians have the highest absolute mean values for cranial breadth, cranial height and mastoid dimensions.

Perhaps the most notable result is that Fuegian crania show quite the opposite tendency in the Tympanic Rim Component compared to Eskimo crania. According to absolute mean values, the low mean score of Fuegians on this factor reflects their deeply indented tympanic rim.

Only Tasmanians have a smaller factor mean score than Fuegians for the Occipital Component. This reflects the fact that Fuegians have a small opisthocranion-inion separation, a small lambda-inion/inion-opisthion ratio and tendency for inion to be higher than endinion. This is consistent with a high incidence of occipital tori on Fuegian crania.

POUNDBURY crania are distinguished from all others by only one factor and it is not temporal-related. A particularly high

factor score on the Flexion-Parietal Breadth Component reflects the fact that Poundbury crania are very broad across the parietals and have the most flexed base of all modern groups.

With Bushman and Eskimo, Poundbury have the smallest factor mean scores on the F.M. Angle Component. The forward rotation of the foramen magnum is greater for Poundbury than for all other modern groups.

Size Component factor mean scores identify Poundbury as one of the 4 groups with comparatively large overall cranial and temporal dimensions.

CHINESE No one factor separates this group from all others. With Andamanese, Chinese have an extreme factor mean score on both the Mastoid Angle and Tympanic Rim Components. This is consistent with Chinese crania having a vertically inclined mastoid process, sagitally inclined tympanic anterior side and quite a thin, indented tympanic plate rim. This is the reverse of the Australian tendency in these 2 factors.

The Petrous Angle Component also contrasts the Chinese with the Australians. With coronally inclined petrous angle and large petrous-tympanic angle, Chinese are grouped with Eskimo and Poundbury at the opposite extreme of the factor mean score distribution to the Australian and 2 African groups which have the most acute petrous and petrous-tympanic angles.

Chinese and Gabon crania possess the most vertically inclined external auditory meatus axis, so these 2 groups have the largest factor mean score on the E.A.M. Component.

Size Component factor mean scores identify Chinese as one of the 4 groups with largest overall cranial and temporal dimensions.

GABON Only one factor distinguishes Gabon from all other groups and it is not temporal-related. The Gabon factor mean score on the F.M.Angle Component is notably high; it is the group with the largest foramen magnum angle (i.e. least rotated forwards).

On the Petrous Angle Component, a small factor mean score places Gabon with Bushman and Australian groups; their crania have particularly small petrous-tympanic and petrous sagittal angles. With Veddah, Gabon has the lowest factor mean score on

the Tympanic-Basion Component reflecting Gabon's sagitally inclined tympanic axis and anteriorly positioned basion.

Gabon has the most vertically inclined external auditory meatus axis but the E.A.M. Component does not separate Gabon from other groups.

Gabon is linked with the groups having high mean scores on the Tympanic Rim Component, (Eskimo, Veddah and Australian) not because the Gabon tympanic plate rim is particularly thick but because it is most protruding, and the tympanic anterior side is coronally inclined (even though Gabon tympanic axis is sagitally inclined).

With Bushman and Andamanese, Gabon have the largest factor mean score on the Occipital Component. For Gabon, this indicates a particularly large opisthocranion-inion separation and an endinion well above inion. Extreme factor mean scores on this component may be related to the presence or absence of parietal bosses and occipital tori. The crania of Bushman, Andamanese and to less extent, Gabon are notable for a high frequency of parietal bosses and lack of occipital tori.

BUSHMAN No one factor separates this group from all others. With the combination of a coronally inclined tympanic and the most posteriorly positioned basion, Bushman have the highest factor mean score on the Tympanic-Basion Component.

Bushman join Gabon and Australian groups with the smallest factor mean scores on the Petrous Angle Component. Bushman have a sagitally inclined petrous angle and the smallest petrous-tympanic angle.

With Gabon and Andamanese, Bushman have the highest factor mean scores for the Occipital Component. Bushman crania have a large separation of endinion above inion and largest lambda-inion/inion-opisthion ratio. Bushman tend to have prominent parietal bosses and no occipital tori.

The Size Component in all analyses identifies Bushman as being one of the three groups smallest in general cranial and temporal dimensions.

Bushman differ notably from Gabon, the other African group, in having a more posteriorly placed foramen magnum and coronally oriented tympanic plate, as well as a more acute mastoid, external auditory meatus and foramen magnum angles. The differences may be less evident if the Bushman sample had

been larger.

VEDDAH No one factor separates this group from all others. With Gabon, Veddah differ from other groups in having particularly low factor mean scores on the Tympanic-Basion Component. This is because these 2 groups have the most sagitally inclined tympanic axes.

Because of a protruding tympanic rim, Veddah is one of the groups with high factor mean scores on the Tympanic Rim Component, (Eskimo, Gabon and Australia);

Veddah, Gabon and Andamanese, with the largest foramen magnum angle absolute means, are separated from other groups by the F.M. Angle Component. However, Veddah factor mean score is considerably less extreme than that of Gabon.

The Size Component identifies Veddah crania as among the three smallest.

ANDAMANESE No one factor separates this group from all others. Though Andamanese have notably the most vertically inclined mastoid process, the Mastoid Angle Component does not separate them from all other groups; with Chinese they are at the opposite extreme of the factor score distribution to Australians.

The Andamanese group has a tympanic plate with sagitally inclined anterior side, and an indented rim which is thinner than that of any other group, but their factor mean score on the Tympanic Rim Component is not small enough to separate them from all other groups.

With Gabon and Bushman, Andamanese have the largest factor mean score on the Occipital Component. For Andamanese, this is because the group has a very small inion-opisthion chord and the largest separation of endinion above inion. The result is consistent with the lack of occipital tori and the occurrence of parietal bosses on Andamanese crania.

The Size Component in all analyses confirm the noticeably small overall cranial and temporal size of the Andamanese. But it is only in the dimension of cranial length (GOL) that Andamanese have an absolute mean value which is smaller than any other group. Bushman and Veddah are as narrow (AUB), and Bushman and Tasmanian are as low (BBH).

6.3.3.4 WHICH VARIABLES CONTRIBUTE TO DISTINGUISHING MODERN GROUPS? Which variables are involved in the factors found to separate different modern human groups from each other?

TEMPORAL FEATURES WHICH CHARACTERISE MODERN GROUPS

AUSTRALIANS
long, most acutely inclined mastoid process axis.
AUSTRALIAN & AFRICAN
most sagittal petrous angle & acute petrous-tympanic angle
ESKIMOS
thickest tympanic plate lateral rim, most coronally oriented anterior side of the tympanic plate, highest temporal squamous
ESKIMOS & BUSHMAN
most coronally oriented tympanic plate axis
ESKIMOS & TASMANIANS
most coronally oriented petrous pyramid
TASMANIANS & BUSHMAN
most acutely inclined external auditory meatus

NON-TEMPORAL FEATURES WHICH CHARACTERISE MODERN GROUPS

POUNDBURY
most flexed base
ESKIMO
longest cranium, longest foramen magnum
FUEGIAN
broadest, highest crania, largest mastoids
TASMANIANS
smallest opisthocranion-inion separation, smallest occipital index
AUSTRALIAN, NEW BRITAIN, TASMANIAN
narrow parietals, wide nasal aperture
GABON
least forward rotated foramen magnum
ESKIMO, POUNDBURY, BUSHMAN
most forward rotated foramen magnum

Chapter 7
DISCRIMINATION OF MODERN HUMAN GROUPS BY TEMPORAL BONE FEATURES:

DISCRIMINANT AND CLUSTER ANALYSES

Discriminant Analysis was applied to the variables considered in Factor Analysis to see if temporal variables could yield discriminant functions which reliably predict group membership, and in particular effectively discriminate Australians.

7.1 THE EFFECT OF SIZE-ADJUSTMENT ON DISCRIMINATION

7.1.1 PURPOSE AND PROCEDURE

7.1.1.1 INTRODUCTION Consideration must be given to the finding from Factor Analysis that half the temporal variables are size-related since they form a positive association with overall cranial size variables on the first factor. In the factor analysis involving 18 temporal variables only, the size-related first factor accounts for merely 24% of the total variance. Nevertheless, the result suggests it may be desirable to adjust variables for size dependence before carrying out Discriminant Analysis, as this may yield a more effective discrimination of Australians and/or population groups in general, and on the basis of a different combination of variables.

In order to adjust the variables for size it was first necessary to establish a satisfactory quantitative measure of cranial size and to decide on the most effective method of correcting the variables for size.

7.1.1.2 ESTIMATION OF CRANIAL SIZE

Two methods were used to estimate cranial size, both on the basis of the Geometric Mean:

$$GM_Y = \text{antilog } 1/n \sum \log Y$$

where the geometric mean, GM_Y, is the antilogarithm of the mean of the logarithms of variable Y, n being the number of variables involved in the calculation.

When variation relative to cranial size was considered in Chapter 5, the measure of cranial size was taken as the

geometric mean obtained from 3 variables, cranial length (GOL), cranial breadth (AUB) and cranial height (BBH). It is referred to here as GM_1.

A second Geometric Mean, GM_2, was calculated using 15 variables (9 temporal and 6 non-temporal) which associated with the size factors in factor analyses 1-5.

Distributions of the two geometric mean values, GM_1 and GM_2, for six and eleven population groups are illustrated in 4 box plots (Figs.7.1.1 to 7.1.4). Based on GM_1, (i.e. on cranial length, breadth and height only), the relative mean size of crania from the 6 large sample populations is

Esk > Chi & Pou > Aus > Gab > And (Fig.7.1.1)

When New Britain and the smaller samples are included the distribution becomes

Fue> Esk> Chi & Pou> Aus> New> Tas> Gab> Ved> Bus> And (Fig.7.1.3)

Although similar distributions result when cranial size is measured by the geometric mean GM_2 calculated from the 15 size dependent variables, there is one notable change. The Eskimo and Tasmanian cranial size is considerably reduced, that of Eskimos no longer being greater than that of Poundbury and Chinese (Figs.7.1.2 & 4). This highlights the fact that of the 15 size-dependent variables associated with GM_2, Eskimos and Tasmanians have relatively small temporal bone dimensions for their overall cranial length, breadth and height. In particular, as can be seen from the box plot of mastoid process volume (Fig.7.1.5 & 6 and Fig.5.3.11b), the mastoid process of Eskimos and Tasmanians is small ~~compared~~ relative to cranial size. (See discussion, Sections 3.2.1 and 5.3.3.11)

7.1.1.3 ADJUSTMENT OF VARIABLES FOR SIZE

Four methods were adopted to adjust variables for size:

(i) All variables were divided by GM_1;

(ii) All variables were divided by GM_2.

(iii) Size-dependent variables only were divided by GM_1;

(iv) Size-dependent variables only were divided by GM_2.

The resulting four sets of variables were tested for skewness and kurtosis and variables transformed as necessary.

Fig.7.1.1. Geometric Means 1--- 6 Groups

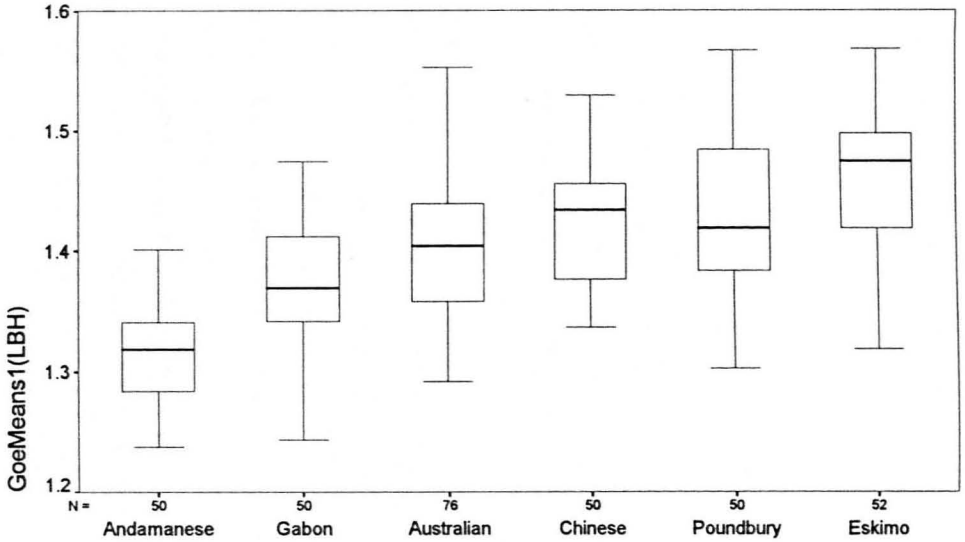


Fig.7.1.2. Geometric Means 2--- 6 Groups

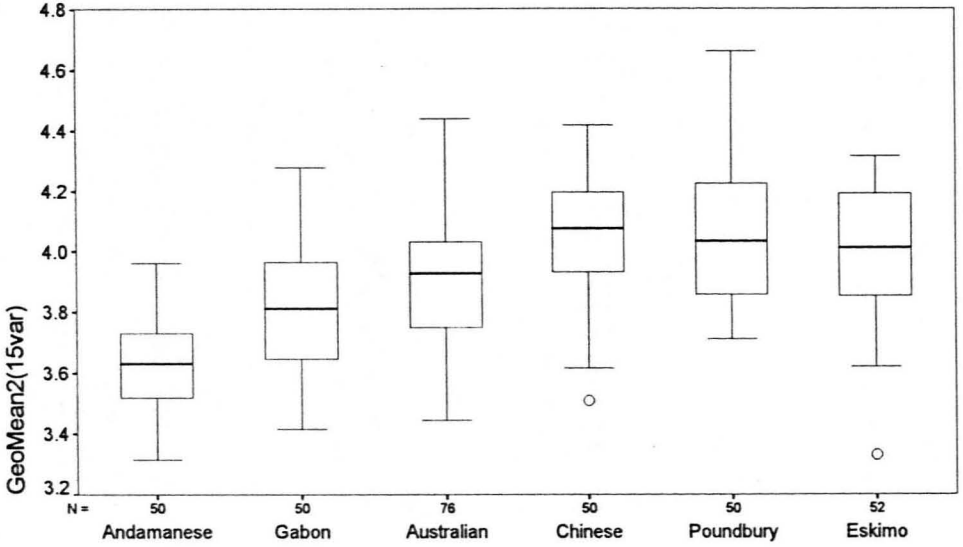


Fig.7.1.3. Geometric Means 1 -- 11 Groups

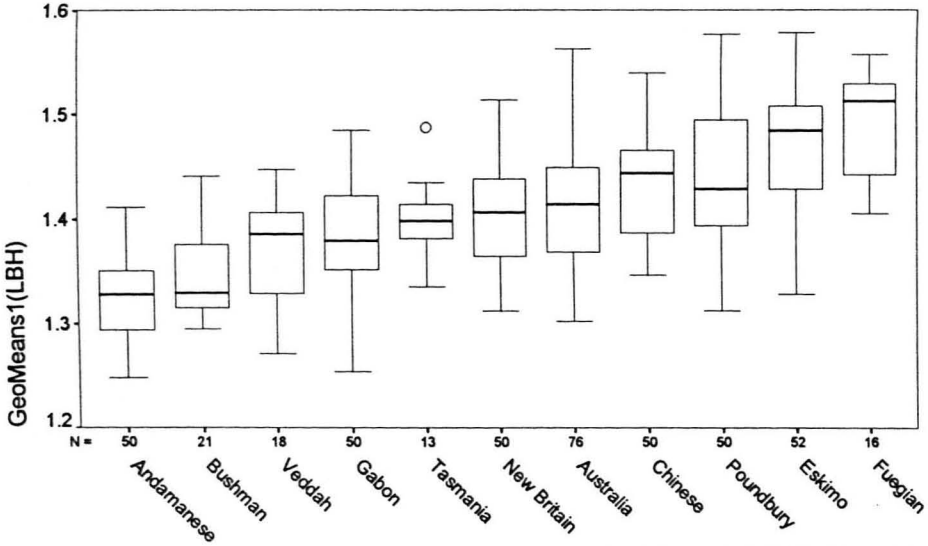


Fig.7.1.4. Geometric Means 2-- 11 Groups

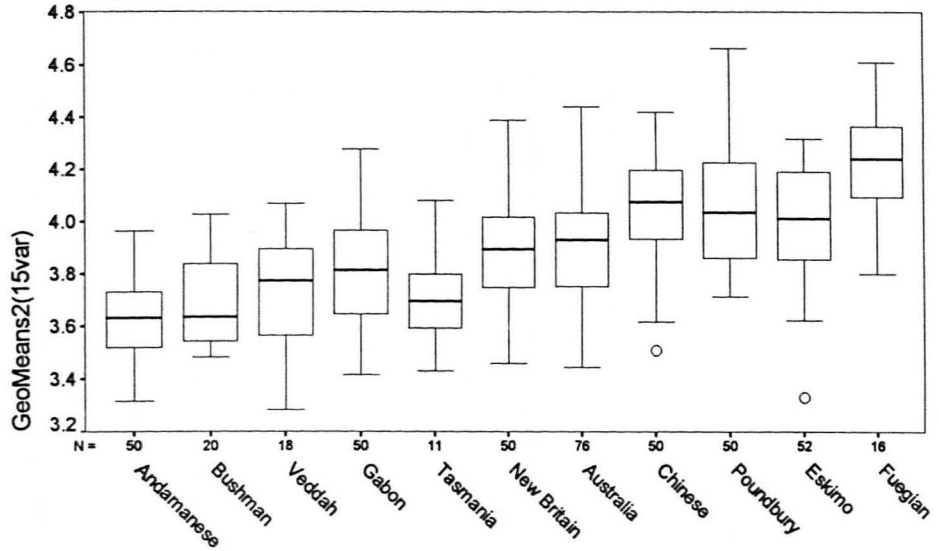


Fig.7.1.5. Mastoid Process Volume --- 6 Groups

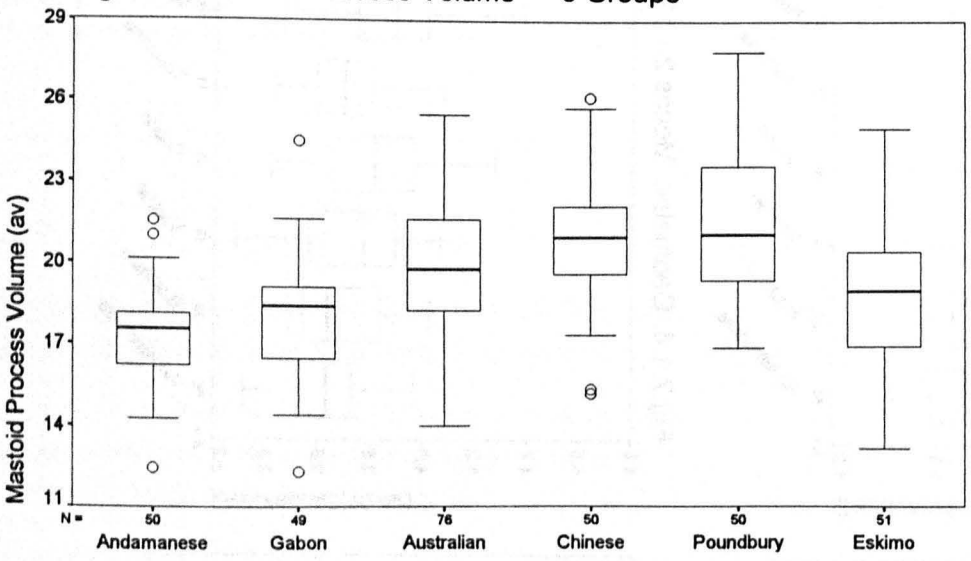
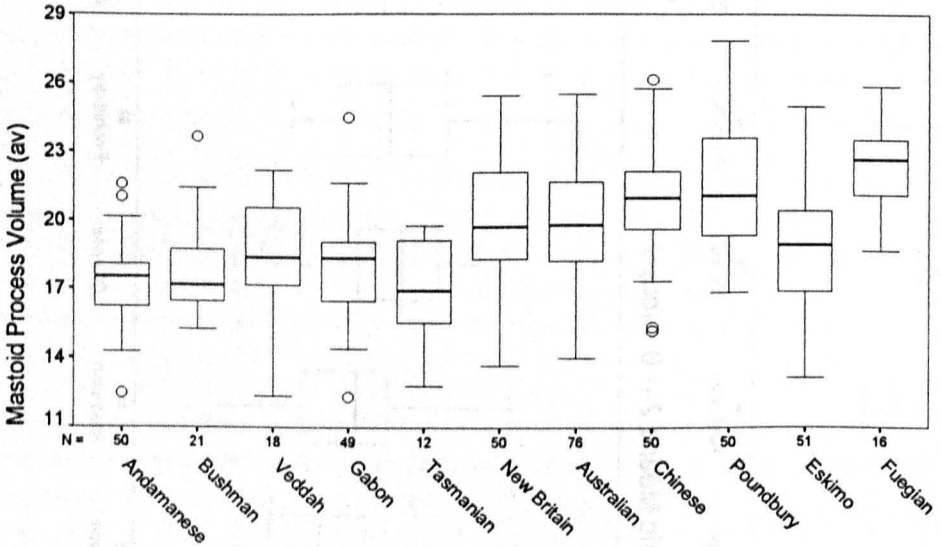


Fig.7.1.6. Mastoid Process Volume --- 11 Groups



7.1.1.4

EVALUATION OF SIZE-ADJUSTMENT IN PREDICTING CLASSIFICATION

Discrimination analysis was carried out on 5 sets of variables. One set consists of the 18 temporal variables, not adjusted for size, which were used in factor analysis; the other 4 sets consist of the same variables, but size-adjusted as in one or other of the 4 methods described above in Section 7.1.1.3.

The method of discriminant analysis used was direct; prior probabilities were based on sample size, and the tolerance level set at .01. In the two analyses involving variables not adjusted for size, the number of variables was reduced from 18 to 17 because one variable, tympanic plate sagittal angle, failed the tolerance test. For the sake of comparison, the number of variables in all analyses was restricted to 17.

The preliminary analyses also revealed that adjusting all the variables for size yielded more effective discrimination than adjusting only size-dependent variables. Consequently, the variable sets generated by size-adjustment methods (iii) and (iv) were not considered further. The remaining 3 sets of 17 temporal variables (two size-adjusted, one not size-adjusted), were submitted to 2 series of discriminant analyses:

1] 6 POPULATION GROUPS (CORE GROUPS)

Andamanese; Australian; Chinese;
Eskimo; Gabon; Poundbury.

This series is limited to geographically distinct groups represented by relatively large samples (at least 50 crania in each sample, 328 crania altogether). Consequently, maximum discrimination was expected for this series of analyses.

2] 11 POPULATION GROUPS

This series comprises 443 crania in the 6 groups listed in 1] together with 5 additional groups:

Bushmen(n=20) Fuegian(n=16) New Britain(n=50)
Tasmanian(n=11) Veddah(n=18)

Discrimination in this series was not expected to be as sharply defined or reliable as in [1], since it included geographically overlapping or close groups (e.g. Bushmen and Gabon; Australian, Tamanian and New Britain). Also, the small sample size of 4 of the additional groups (none over 20),

raised the possibility of overfitting, sample bias and the likelihood of a disproportionately low percentage of correct classifications for the small groups, prior probabilities having been set by sample size (Hedderson, 1991:141, Tabachnick & Fidell, 1989:511, 518).

7.1.2 RESULTS AND DISCUSSION

The effect of size-adjustment on discrimination power was assessed by comparing the percentage of correct classification predictions for groups in general and Australians in particular which resulted from the 6 analyses (Table 7.1.1 for 6 Groups, Table 7.1.2 for 11 Groups).

Which was the most effective size-correction method?

It makes little difference which method of size-adjustment is used. For 6 groups, method 1 with GM_1 yields 2.6% greater classification accuracy for Australians and 1.22% overall than Method 2 (Table 7.1.1, columns b) & c)). When 11 groups are involved, the 2 methods yield no difference in classification accuracy for Australians; for the total sample, method 2 with GM_2 produces greater classification accuracy but by merely .22%, a negligible difference (Table 7.1.2, columns b) & c)).

Is discrimination improved by adjusting variables for size?

Differences are minimal or non-existent. For 6 groups, adjusting variables for size decreases classification accuracy by 1.4%-4.0% for Australians and by 1.83%-3.05% overall (Table 7.1.1, column a) compared to columns b) & c)). For 11 groups, Australian classification accuracy is the same whether variables are size-adjusted or not; overall classification accuracy is increased by less than 1% when variables are size-adjusted (Tables 7.1.1 & 2, column a) compared to columns b) & c)).

Are the variables which distinguish the Australians the same in all analyses? Taking the group means of discriminant scores as criteria, the single discriminant function which best distinguishes Australian crania is number 3 or 4. The combination of variables which have their highest correlation with the distinguishing function varies slightly from one analysis to another but always includes mastoid process depth,

length and axis angle or their relative equivalents in the size adjusted analyses. Petrous sagittal angle (or its relative equivalent) is included in all but one combination. Relative petrous-tympanic angle, glenoid fossa medial-lateral length (or relative equivalent) and relative temporal squamous height also appear in the distinguishing combination in one or two analyses (Tables 7.1.1 & 7.1.2.).

Are Australians more reliably discriminated from the 6 groups or from the 11 groups?

Accuracy of predictions is greater for each of the 6 groups analyses than the equivalent 11 groups analyses by 9.2%-13.2% for Australians and by 7.99%-11.94% overall (Tables 7.1.1 & 7.1.2.). This is consistent with the small size of 4 of the 11 groups and the fact that the 11 groups are less geographically distinct than the 6 groups.

Are Australians more effectively discriminated than other modern groups by the 17 temporal variables?

The percentage of Australian cases classified correctly is higher than the total percentage of cases classified correctly in the same analysis, whether or not variables had been size-adjusted. This must be attributed at least in part to the fact that the Australian sample (n=76) was larger than any other. Even so, Andamanese consistently have a higher percentage of correctly classified cases than Australians; Eskimo classification was more accurate in all but one analysis. This suggests that the Eskimo and Andamanese differ more from other modern groups in temporal features than do the Australians.

Is discrimination improved by standardizing variables?

The sets of variables which yielded best discriminant results (non-size-adjusted for 6 groups, size adjusted by GM_2 for 11 groups) were standardized using Z-scores. The classification results were identical to those of the corresponding analyses of unstandardized variables.

Does size-adjustment have more effect on discrimination efficiency if the analysis is based on non-temporal rather than temporal variables?

The same set of analyses was repeated, substituting 17

TABLE 7:1.1

EFFECTIVENESS OF SIZE ADJUSTMENT IN PREDICTING CLASSIFICATION OF 6 POPULATION GROUPS BY 17 TEMPORAL VARIABLES.

	17 TEMPORAL VARIABLES		
	a) NON-SIZE-ADJUSTED	b) SIZE-ADJUSTED by method 1 (LBH)	c) SIZE-CORRECTED by method 2 (15 vars)
% CORRECT PREDICTION for Australians	88.20%	86.80%	84.20%
for all 6 groups	80.79%	78.96%	77.74%
Discriminant Function & its highest correlated variables which best* separate Australians. (Cor. coeffs. quoted)	D. Fn. 4 MPL -.56 MANG .45 GML -.45 MPD -.42	D. Fn. 3 MPL -.56 MANG .49 PANGS .46 MPD -.34 GML -.33	D. Fn. 3 MANG -.58 MPL .54 PANGS -.52 PTANG -.44 TSQH -.35

* based on group means of discriminant scores.

TABLE 7:1.2

EFFECTIVENESS OF SIZE ADJUSTMENT IN PREDICTING CLASSIFICATION OF 11 POPULATION GROUPS BY 17 TEMPORAL VARIABLES.

	17 TEMPORAL VARIABLES		
	a) NON-SIZE-ADJUSTED	b) SIZE-ADJUSTED by method 1 (LBH)	c) SIZE-CORRECTED by method 2 (15 vars)
% CORRECT PREDICTION for Australians	75.00%	75.00%	75.00%
for all 11 groups	68.85%	69.53%	69.75%
Discriminant Function & its highest correlated variables which best* separate Australians. (cor. coeffs. quoted)	D. Fn. 4 MPL -.61 PANGS .46 MANG .40 MPD -.33	D. Fn. 4 MPL -.57 PANGS .52 MANG .43 MPD -.33	D. Fn. 4 MPL .56 PANGS -.55 MANG -.47 PTANG -.42 MPD .30

* based on group means of discriminant scores.

TABLE 7:1.3

EFFECTIVENESS OF SIZE ADJUSTMENT IN PREDICTING CLASSIFICATION OF 6 POPULATION GROUPS BY 17 NON-TEMPORAL VARIABLES.

	17 NON-TEMPORAL VARIABLES		
	d) NON-SIZE-ADJUSTED	e) SIZE-ADJUSTED by method 1 (LBH)	f) SIZE-CORRECTED by method 2 (15 vars)
% CORRECT PREDICTION for Australians	89.50%	90.80%	84.20%
for all 6 groups	88.11%	90.55%	84.15%
Discriminant Function & its highest correlated variables which best* separate Australians. (Cor. coeffs. quoted)	D. Fn. 2 XCB -.41 NLB .40	D. Fn. 1 zXCB .62 zWCB .20	D. Fn. 2 LgXCB -.54

* based on group means of discriminant scores.

TABLE 7:1.4

EFFECTIVENESS OF SIZE ADJUSTMENT IN PREDICTING CLASSIFICATION OF 11 POPULATION GROUPS BY 17 NON-TEMPORAL VARIABLES.

	17 NON-TEMPORAL VARIABLES		
	d) NON-SIZE-ADJUSTED	e) SIZE-ADJUSTED by method 1 (LBH)	f) SIZE-CORRECTED by method 2 (15 vars)
% CORRECT PREDICTION for Australians	80.30%	84.20%	78.90%
for all 11 groups	78.56%	79.91%	75.85%
Discriminant Function & its highest correlated variables which best* separate Australians. (cor. coeffs. quoted)	D. Fn. 2 XCB -.44	D. Fn. 2 zXCB .73	D. Fn. 2 LgXCB -.61

* based on group means of discriminant scores.

non-temporal variables for the 17 temporal variables. The non-temporal variables were those used in factor analysis (or their size-adjusted equivalents). Cranial length (GOL) was not included because it failed the tolerance test in analyses involving size-adjusted variables.

Similar trends result from the non-temporal variable analyses as from temporal variable analyses (Tables 7.1.3 & 4). (i) Discrimination of Australians and overall is more effective when 6 rather than 11 groups are involved.

(ii) Australians are more readily discriminated than other modern groups in general, but less so than Eskimos and Andamanese.

(iii) Size-adjusting non-temporal variables makes only slight differences to classification accuracy. Discrimination using non-temporal variables is more effective if the variables have been size-adjusted by method 1. The improvement in classification for Australians is by 1.3% (6 groups) and 3.9% (11 groups), and overall by 2.44% (6 groups) and 1.35% (11 groups). Size-adjustment by method 2 decreases discrimination efficiency.

(iv) Maximum parietal breadth is the only non-temporal variable which consistently has its highest loading on the single discriminant function which, according to discriminant score group means, best separates the Australians.

7.1.3 SUMMARY: Size-Adjustment Effect on Discriminant Analysis

On the basis of the results from discriminant analyses involving 3 sets of 17 temporal variables (one set not size-adjusted, the other sets adjusted for size by two different methods) and equivalent analyses involving 17 non-temporal variables it can be concluded:

(i) If variables are size-adjusted, discrimination of Australians by temporal variables is either unaffected (11 groups) or decreased slightly by up to 4% (6 groups). The same is true for the groups overall. This outcome is consistent with the Factor Analysis finding that although there is some dependence on size among temporal variables, more than 3/4 of the variation is unrelated to size.

(ii) Discrimination of Australians by non-temporal

variables is slightly enhanced by up to 3.9% if variables are size-adjusted by method 1, but slightly decreased by the alternative method 2. This is consistent with the non-temporal variables being more dependent than the temporal variables on cranial size.

(iii) Mastoid process length, depth and axis angle, and petrous sagittal angle are the temporal predictors most consistently with highest correlation on the single discriminant function (3 or 4) which best discriminates Australians. This is confirmation of the factor analysis finding that mastoid axis angle and to less extent, mastoid length are the variables associated with the factor which best separates Australians.

(iv) Maximum parietal breadth is the non-temporal predictor associated with the single discriminant function 1 or 2 which most effectively discriminates Australians.

(v) Whether the variables are temporal or non-temporal, Australians are more effectively discriminated in the 6 groups analysis than in the 11 groups analysis.

(vi) In both the 6 and 11 Groups analyses, whether the variables are temporal or non-temporal, size-adjusted or not, Australians are more effectively discriminated than groups in general, but less so than are Eskimo or Andamanese.

(vii) Standardizing the variables does not alter the discrimination effectiveness.

(viii) Australian crania are intermediate in overall cranial size as measured by the two geometric means defined in this study.

(ix) Eskimos and Tasmanians have relatively small temporal features (in particular, a small mastoid process) since inclusion of temporal dimensions in the estimation of cranial size yields much smaller cranial size means for these two groups compared to other groups than by estimation based on cranial length, breadth and height only.

7.2 DISCRIMINATION OF AUSTRALIANS AND OTHER MODERN GROUPS BY 17 TEMPORAL VARIABLES

7.2.1 PURPOSE AND PROCEDURE

This section examines in detail the outcome of direct discriminant function analysis based on 17 temporal variables for (i) 328 crania from 6 modern groups (large population samples, geographically distinct)

(ii) 443 crania from 11 modern groups (New Britain and 4 small population samples also included).

The variables used are not size-adjusted since it has been established in the previous section that size-adjustment of the temporal variables in this study has little effect on discrimination of modern crania both as to the accuracy of classification prediction and the identity of the most important predictors. (Accuracy is unaffected when the analysis involves 11 groups and slightly decreased when 6 groups are involved.)

The 17 temporal variables are listed in Table 7.2.1.1. Variable codes beginning with "Q" or "L" identify variables transformed by square root or $\log_{10}$ as indicated necessary by skewness and kurtosis tests. From the values of Wilks' Lambda and univariate F-ratio (Table 7.2.1.1) the hypothesis that all group means are equal can be rejected for every variable in both the 6 groups and 11 groups analyses since all observed significance levels are less than .05 (Norusis 1993b:4). All values were significant at p=.000 except for those of two variables, anteriority of basion and external auditory meatus axis angle. Their comparatively high Wilks' Lambda values and low F-ratios indicate small difference in their group means and weak discriminating power compared to the other 17 predictors. Tympanic plate lateral rim thickness is likely to be the predictor with strongest discriminating power since its notably low Wilks' Lambda and high F value indicate it is the variable with greatest difference in group means.

The direct (standard) discriminant analysis method was used; prior probabilities were based on group size, and the tolerance was set at .01. All 17 variables passed the tolerance test in both analyses. In the investigation of the effect of size-adjustment on discrimination, it was found that the variable tympanic plate sagittal angle had insufficient

TABLE 7.2.1.1

TEMPORAL PREDICTOR VARIABLES USED IN DISCRIMINANT ANALYSIS.

1] 6 GROUPS, 17 TEMPORAL VARIABLES NOT SIZE-ADJUSTED.
Wilks' Lambda (U-statistic) and univariate F-ratio
with 5 and 322 degrees of freedom.

Variable	Wilks' Lambda	F	Significance
ATANGS	.713	25.867	.000
BANT	**.957**	**2.928**	**.013**
EANG	**.960**	**2.662**	**.022**
LMPW	.702	27.320	.000
MANG	.810	15.117	.000
MPD	.844	11.866	.000
MPL	.774	18.774	.000
PANGS	.771	19.100	.000
PPL	.819	14.197	.000
PTANG	.880	8.779	.000
QGAP	.758	20.526	.000
QGML	.832	13.043	.000
QTPH	.695	28.312	.000
QTPL	.876	9.101	.000
QTTHK	**.456**	**76.844**	**.000**
TIND	.782	17.964	.000
TSQH	**.672**	**31.442**	**.000**

TEMPORAL PREDICTOR VARIABLES USED IN DISCRIMINANT ANALYSIS.

2] 11 GROUPS, 17 TEMPORAL VARIABLES NOT SIZE ADJUSTED
Wilks' Lambda (U-statistic) and univariate F-ratio
with 10 and 432 degrees of freedom

Variable	Wilks' Lambda	F	Significance
ATANGS	.754	14.101	.000
BANT	**.942**	**2.657**	**.004**
EANG	**.941**	**2.693**	**.003**
LMPW	.690	19.399	.000
MANG	.828	8.976	.000
MPD	.843	8.050	.000
MPL	.748	14.578	.000
PANGS	.782	12.024	.000
PLL	.801	10.724	.000
PTANG	.861	6.960	.000
QGAP	.680	20.373	.000
QGML	.756	13.929	.000
QTPH	.715	17.236	.000
QTPL	.791	11.384	.000
QTTHK	**.517**	**40.305**	**.000**
TIND	.773	12.722	.000
TSQH	**.648**	**23.463**	**.000**

tolerance to be included. This reduces to 17 the number of temporal variables in discriminant analysis compared to 18 in the factor analysis.

7.2.2 RESULTS AND DISCUSSION: 6 GROUPS DISCRIMINATION ANALYSIS (Tables 7.2.1.2-9 Figs.7.2.1.1-8)

The discriminant analysis yields 5 functions, the first 3 accounting for a total of 85.3% of the between groups variability (Table 7.2.1.2). The eigen values imply the discriminating value of this analysis is reliable since values >.4 are considered excellent (Hedderson 1991:146). The last function is very weak but for the other four functions, the low Wilks' Lambda values and corresponding high Chi-square values, all significant at p=.0000, indicate highly reliable relationships between groups and predictors. When all functions are considered, 94.0% of the variance in the predicting variables is accounted for by the differences between groups (Wilks' Lambda = .060).

Which discriminant function(s) and predictors identify Australians and other groups?

The group means of function scores suggest that the single discriminant function most effective in distinguishing Australians from other groups is the third (Table 7.2.1.4). Function 3 accounts for only 15% of the between groups variance but is a reliable discriminant function ($Chi^2(45)$= 317.2, p=.0000, Table 7.2.1.2). From the pooled-within-groups correlation between predictors and functions, the predictors with their maximum loading on Function 3 are mastoid process length, depth and angle and glenoid fossa medial/lateral length (Table 7.2.1.3). In factor analysis it was found that two of these variables, mastoid process length and angle, best separated the Australians.

Considering the absolute means of the four main predictors associated with Function 3 (Table 7.2.1.5), and compared to the other 5 groups, Australians have the deepest, second longest and most acutely angled mastoid process, and the second widest (medial/lateral) glenoid fossa. 4 of the 6 possible correlations between the four predictors were moderate and significant at p<.001; the other 2 correlations, of mastoid angle with mastoid length and with glenoid fossa

TABLE 7.2.1.2 6 GROUPS, 17 TEMPORAL VARIABLES, DISCRIMINANT ANALYSIS OF VARIANCE

Function	Eigenvalue	% of Variance	Canonical Correlation
1	1.81	42.6	.80
2	1.18	27.7	.74
3	0.64	15.0	.62
4	0.55	12.9	.60
5	0.08	1.8	.27

After Fn.	Wilks'Lambda	Chi-square	DF	Significance
0	.060	889.2	85	.0000
1	.168	562.9	64	.0000
2	.366	317.2	45	.0000
3	.600	161.4	28	.0000
4	.929	23.4	13	.0373

TABLE 7.2.1.3.
6 GROUPS, 17 TEMPORAL PREDICTORS, STRUCTURE MATRIX.

Pooled-within-groups correlations between discriminant variables and the 5 canonical discriminant functions. Values recorded are each variable's maximum loading* and other loadings > .300 (Tabachnick and Fidell 1989:539).

	FUNC 1	FUNC 2	FUNC 3	FUNC 4	FUNC 5
QTTHK	.760*	.305			
QGAP	.326*		-.309		
(BANT)	(.139*)				
TSQH		.580*			
QTPH		.505*		-.475	
LMPW		.448*	-.405		
(PTANG)		(.257*)			
MPL			-.558*		
MANG			.448*		
QGML			-.445*		
MPD			-.423*		
PANGS		.357		.456*	
TIND				.430*	
PPL				-.421*	
ATANGS	.382		.335		.580*
QTPL					-.353*
EANG					-.320*

TABLE 7.2.1.4 6 GROUPS, 17 TEMPORAL PREDICTORS, GROUP MEANS OF DISCRIMINANT FUNCTION SCORES.

GROUP	FUNC 1	FUNC 2	FUNC 3	FUNC 4	FUNC 5
AND	-1.33	-1.04	.74	1.21	.04
AUS	.75	-.93	-1.15	.07	-.11
CHI	-1.36	1.52	-.11	-.13	-.43
ESK	2.51	.82	.80	.30	-.01
GAB	-.36	-1.01	.79	-1.39	.03
POU	-.70	1.08	-.52	-.10	.54

TABLE 7.2.1.5

GROUP MEANS, 6 GROUPS, TEMPORAL VARIABLES ON DISCRIMINANT FUNCTIONS 1, 2, & 3.

GROUP	MANG	MPD	MPL	QGML	QTTHK	QGAP	TSQH	QTPH	LMPW
And	73.200	11.270	27.530	4.742	1.196	3.990	41.32	3.897	1.218
Aus	**64.520**	**12.876**	**32.518**	**4.942**	**1.758**	**4.212**	**43.45**	**4.010**	**1.269**
Chi	70.220	12.680	32.394	4.927	1.492	4.151	48.42	4.327	1.340
Esk	67.327	12.313	29.812	4.883	2.144	4.265	49.78	4.122	1.246
Gab	69.660	10.812	29.734	4.778	1.505	4.068	43.88	4.143	1.250
Pou	66.850	12.742	33.406	4.953	1.612	4.160	47.05	4.234	1.346
Total	68.296	12.177	31.021	4.876	1.632	4.147	45.52	4.113	1.277

TABLE 7.2.1.6 6 GROUPS, CORRELATION COEFFICIENTS FOR TEMPORAL VARIABLES ON DISCRIMINANT FUNCTIONS 1,2,3.

	MANG	MPD	MPL	QGML	QTTHK	TSQH	QTPH
MANG	1.000						
MPD	-.184**	1.000					
MPL	-.401***	.574***	1.000				
QGML	.110*	.450***	.421***	1.000			
QTTHK					1.000		
QGAP					.458***		
TSQH						1.000	
QTPH						.304***	1.000
LMPW						.360***	.344***

* p < .05 ** p < .01 *** p < .001 (2-tailed significance)

width, were both weak but significant at $p<.01$ and $p<.05$ respectively (Table 7.2.1.6).

The first function accounts for far more between-groups variance than any other function (42.7%) and singles out the Eskimo group from all others (Tables 7.2.1.2 & 4). Tympanic plate lateral rim thickness (the predictor with greatest between-groups variance, Table 7.2.1.1) has its highest loading on this function (Table 7.2.1.3). This reiterates the finding in factor analysis that Eskimos are distinguished by the exceptional thickness of their tympanic rim. Glenoid fossa anterior/posterior length and anteriority of basion also make a weak contribution to the first function. Eskimos have the largest absolute mean for glenoid fossa anterior/posterior length and moderate correlation exists between that variable and tympanic plate lateral rim thickness ($r=.458$, $p<.001$) (Tables 7.2.1.5 & 7.2.1.6).

The 3 variables with the second third and fourth greatest between-groups variance, (temporal squamous height, mastoid process width and tympanic plate height), have their highest loadings on function 2. The Chinese group is the one best separated by this single function (Tables 7.2.1.4).

To assess the combined discriminating effect of these first 3 functions, scatter plots of discriminant score distributions, and of group centroids (group means of discriminant scores) were examined.

FUNCTION 2 VS.FUNCTION 1. (Figs.7.2.1.1 & 2). No group has a distribution of discriminant scores which is entirely distinct from all others, but the Eskimo distribution is the most separate (Fig.7.2.1.1). Consideration of the identity of predictor variables on functions 1 & 2 and their absolute group mean values, shows this is largely because of the thick tympanic plate rim and high temporal squamous of Eskimos (Tables 7.2.1.3 & 5). The Australian distribution is less distinct than that of the Eskimos.

In the plot of group centroids of function 1 & 2 (Figs.7.2.1.2), not only are the Eskimos different to all other groups, but Chinese and Poundbury are paired (high temporal squamous and tympanic plate, and comparatively thin tympanic rim) leaving Australians with Gabon and Andamanese groups (low temporal squamous and tympanic plate).

Fig.7.2.1.1. Discriminant Fn. 1 & 2 Scores

6 Groups, 17 Temporal Predictors

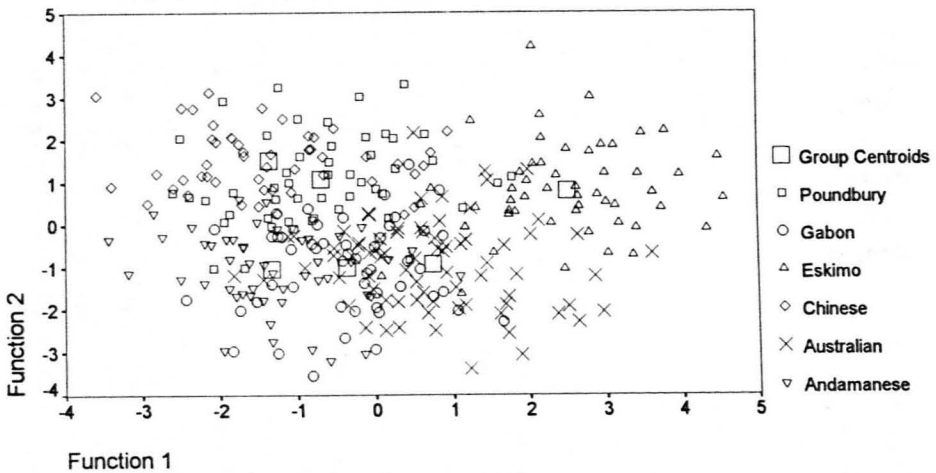


Fig.7.2.1.3. Discriminant Fn. 1 & 3 Scores

6 Groups, 17 Temporal Predictors

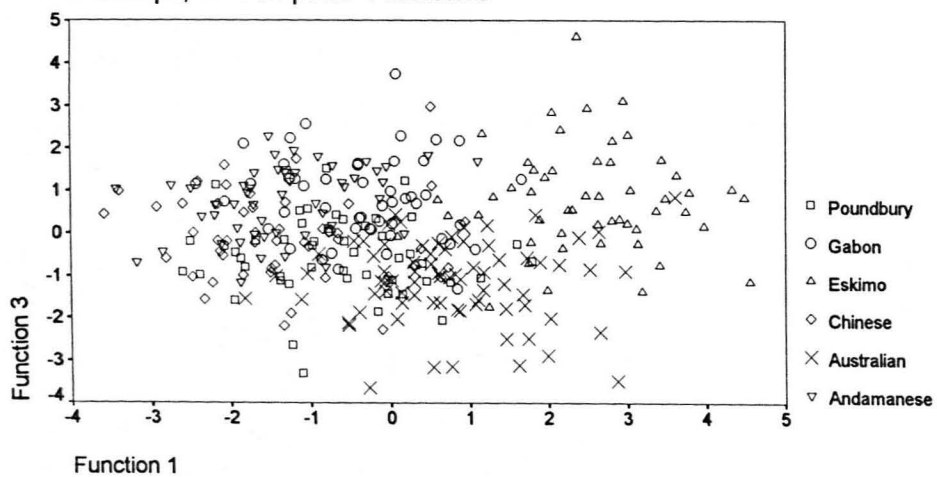


Fig.7.2.1.2. Group means of Discriminant Scores

6 Groups, 17 Temporal Predictors

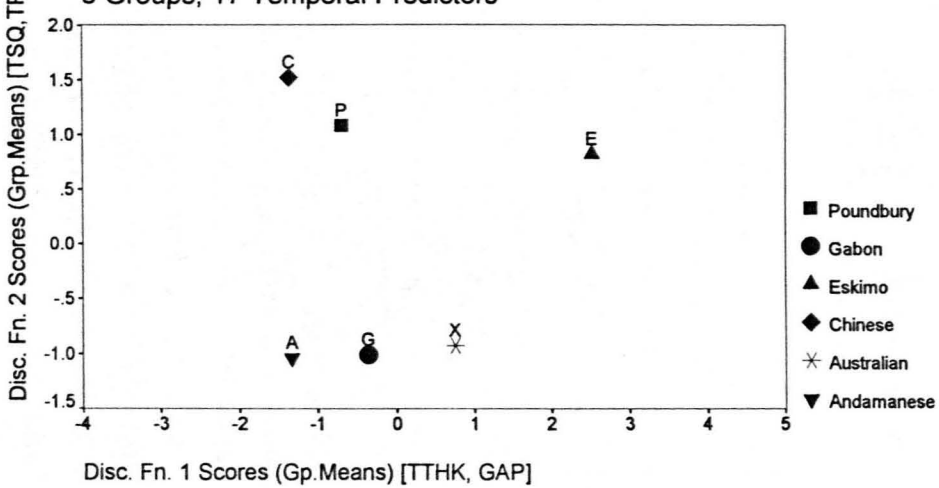


Fig.7.2.1.4. Group means of Discriminant Scores

6 Groups, 17 Temporal Predictors

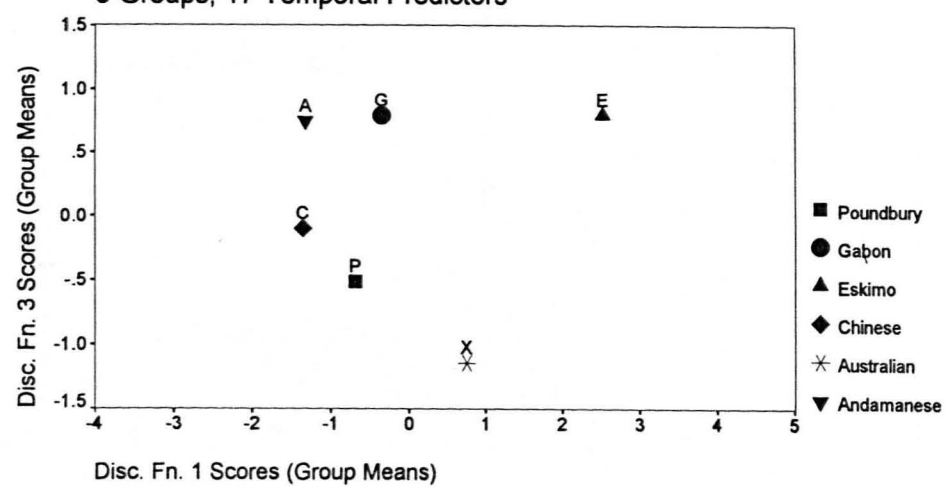


Fig.7.2.1.5 Discriminant Fn. 2 & 3 Scores

6 Groups, 17 Temporal Predictors

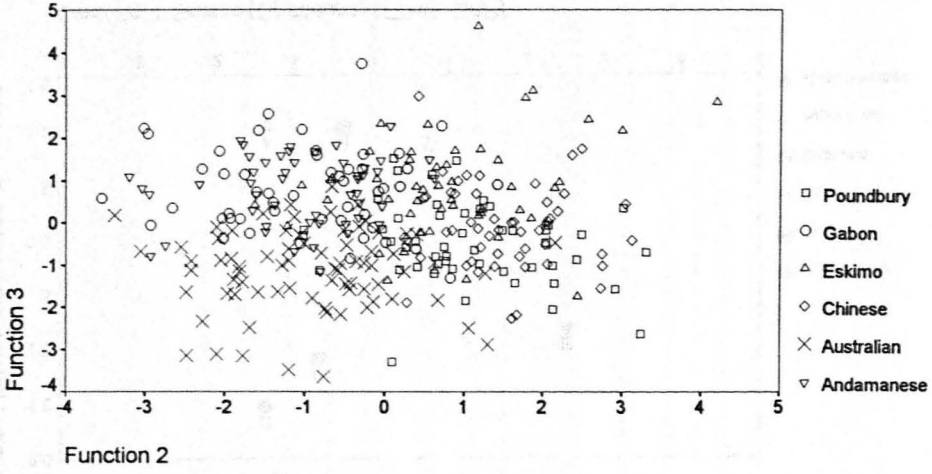


Fig.7.2.1.6. Group means of Discriminant Scores

6 Groups, 17 Temporal Predictors

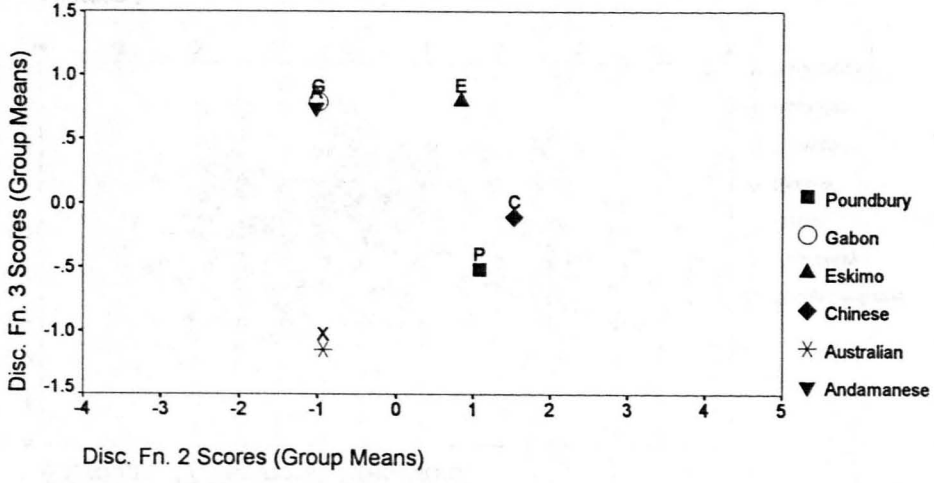
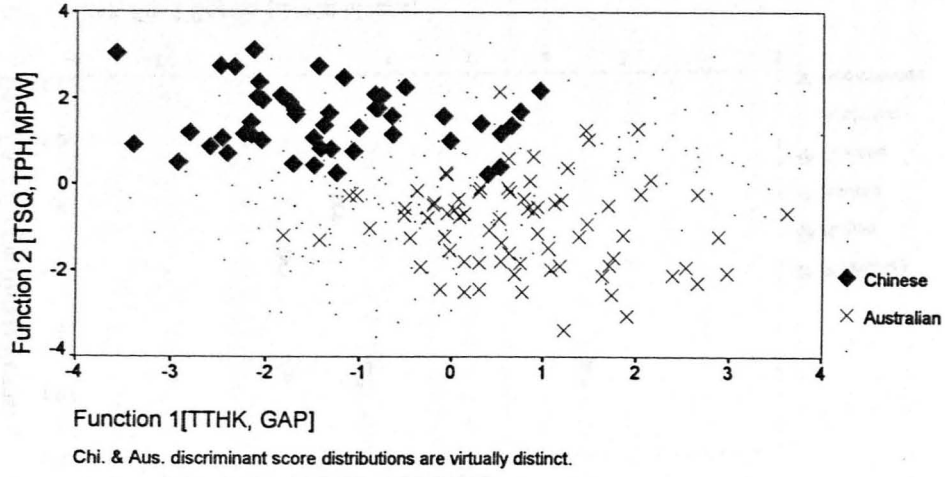


Fig.7.2.1.7. Discriminant Fn. 1 & 2 Scores

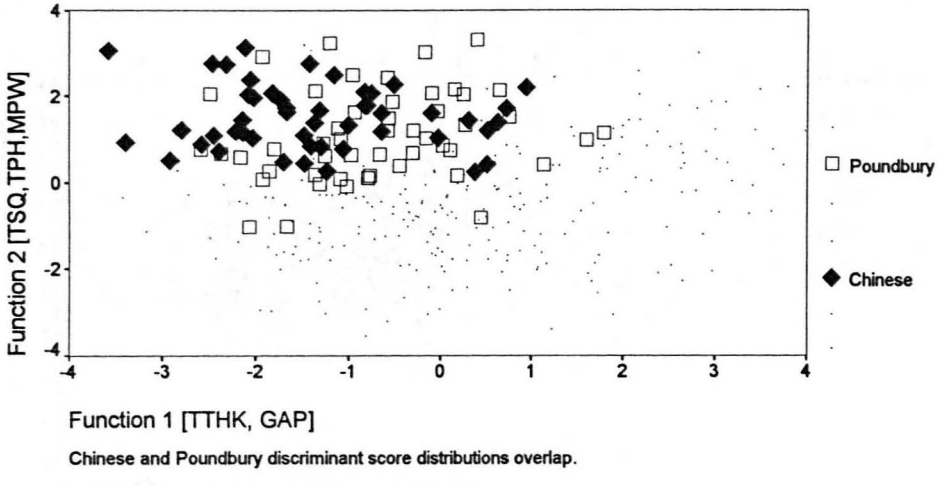
2 of 6 Groups, 17 Temporal Predictors



Chi. & Aus. discriminant score distributions are virtually distinct.

Fig.7.2.1.8. Discriminant Fn. 1 & 2 Scores

2 of 6 Groups, 17 Temporal Predictors



Chinese and Poundbury discriminant score distributions overlap.

FUNCTION 3 VS.FUNCTION 1. (Figs.7.2.1.3 & 4). The improvement in distinguishing the Australians by plotting function 3 against function 1 is less obvious in the plot of discriminant scores than in the simpler main effect plot of centroids (Figs.7.2.1.4). Because of their very high discriminant function 1 group mean values (reflecting a particularly thick tympanic rim), Eskimos are again depicted as the group most different to all others. The separation of Australians is not so extreme; it depends primarily on function 3 but also on function 1; the combination of a wide glenoid fossa and a long, deep, acute angled mastoid process contribute to the separation of Australians from all other groups. The separation from Eskimos is enhanced by the Australian tympanic plate rim being comparatively less robust; the separation from the remaining four groups is enhanced by the Australian tympanic plate being comparatively more robust.

FUNCTION 3 VS.FUNCTION 2. (Figs.7.2.1.5 & 6). There is more overlap of discriminant score distributions when function 2 and 3 are plotted than in the two previous distribution plots (Figs.7.2.1.5). Without function 1, Eskimos are no longer distinct. However, according to the plot of group centroids (Figs.7.2.1.6), Australians are separated to some degree from all other groups by function 3 and associated predictors of glenoid fossa width and mastoid orientation and dimensions. The distinction from Eskimos, Poundbury and Chinese is enhanced by the smaller Australian discriminant mean value on function 2 due to the comparatively low temporal squamous and tympanic plate of Australians (Table 7.2.1.4 & 5). Gabon and Andamanese are inseparable on the basis of function 1 and 2.

CHINESE/AUSTRALIAN DISTRIBUTION. Although the Australian distribution of mean scores is not completely separate from all other groups, it was found to be most different to and virtually distinct from the Chinese distribution in all 3 plots of discriminant scores. This is illustrated in the plot of function 1 and 2, recoded to highlight Australian and Chinese scores (Fig.7.2.1.7). This suggests that the Chinese are the group least like Australians in temporal features, notably in a considerably thinner tympanic rim, higher temporal squamous, higher tympanic plate, large mastoid angle. Factor analysis indicated Chinese and Andamanese are the

groups most distinct from Australians on the basis of mastoid angle.

CHINESE/POUNDBURY DISTRIBUTION. It was noticed in all three plots of group centroids that Poundbury and Chinese mean values are similar. To find out if this is also true of their discriminant score distributions, the plot of function 1 and 2 discriminant scores was reconsidered (Fig.7.2.1.8). There is almost complete overlap of the two distributions, implying that of the 6 groups, Poundbury and Chinese are least able to be distinguished by temporal variables. They are alike in mastoid dimensions and orientation, glenoid fossa dimensions, tympanic plate height and temporal squamous height. They are least alike in tympanic plate rim thickness.

CLASSIFICATION ACCURACY

1. How accurately can the Australians and other 5 groups be classified on the basis of discrimination by temporal variables? Discrimination based on 17 temporal variables has produced 88.2% correct classification for Australians and 80.8% correct classification overall (Table 7.2.1.7). However, this does not mean that Australians are more readily distinguished by temporal features than are all other modern groups. Both Andamanese and Eskimos have higher prediction accuracy than Australians. Misclassified Australians appeared in all groups except Chinese, a result consistent with the lack of overlap of their respective discriminant score distributions (Fig.7.2.1.7).

Predicted group membership is least accurate for Poundbury (56.0%) and Chinese (76.0%), and most of Poundbury's misclassifications were as Chinese and vice versa. This reflects the similarity of temporal features of these two population groups (Fig.7.2.1.8). Classification accuracy for Gabon crania (80.0%), is only slightly better than that for Chinese; most misclassified Gabon crania(10.0%) are grouped with Australians.

2. How reliable is the estimate of misclassification rate?

Prediction accuracy of the discriminant function when applied to the sample from which it was derived is an inflated estimate of the true performance in the population. To obtain

TABLE 7.2.1.7 6 GROUPS, 17 TEMPORAL PREDICTORS, OBSERVED CLASSIFICATION RESULTS.

No. of Group	Cases	Predicted Group Membership AND	AUS	CHI	ESK	GAB	POU
AND	50	47	0	1	0	2	0
		94.0%	.0%	2.0%	.0%	4.0%	.0%
AUS	76	3	67	0	2	1	3
		3.9%	88.2%	.0%	2.6%	1.3%	3.9%
CHI	50	0	1	38	1	1	9
		.0%	2.0%	76.0%	2.0%	2.0%	18.0%
ESK	52	0	4	0	45	1	2
		.0%	7.7%	.0%	86.5%	1.9%	3.8%
GAB	50	2	5	2	0	40	1
		4.0%	10.0%	4.0%	.0%	80.0%	2.0%
POU	50	3	1	13	2	3	28
		6.0%	2.0%	26.0%	4.0%	6.0%	56.0%
Total No. 328					Total Correctly Classified:		80.8%

TABLE 7.2.1.8 Results of the Jackknife Method of estimating misclassification rates.
Each Australian case was classified in turn, having not been included in the calculation of the discriminant function.

	No.in sample	No.correctly classified	% correctly classified
Known Australians	75	64 - 67	85.3% -89.3%
Unidentified Australian	1 (x 76)	60/76	79.0%
Total sample	327	265 - 261	79.8% - 81.0%

TABLE 7.2.1.9
6 GROUPS, 17 TEMPORAL PREDICTORS, CORRECT CLASSIFICATIONS BY ANALYSIS COMPARED TO THAT EXPECTED BY CHANCE.

	And	Aus	Chi	Esk	Gab	Pou	TOTAL
No. in GROUP	50	76	50	52	50	50	328
ANALYSIS							
No.	47	67	38	45	40	28	305
%	94.0%	88.2% (79.0%*)	76.0%	86.5%	80.0%	56.0%	80.8%
CHANCE							
No.	7.6	17.6	7.6	8.2	7.6	7.6	56.3
%	15.2%	23.2%	15.2%	15.8%	15.2%	15.2%	17.2%

(* estimated from the Jackknife Method)

an improved estimate of the misclassification rate, the Jackknife method of cross-validation was applied (Norusis 1993b:14). Each of the 76 cases from the Australian sample was in turn left out, the calculation of the discriminant function being based on the remaining 75 cases. The omitted case was then classified. Since the test case does not contribute to the calculation of the function, the misclassification observed is less biassed. Of the 76 Australian cases 60 (79.0%) were classified correctly (Table 7.2.1.8). This is 9.2% less than the original results from discrimination based on all classified cases.

3. How well does the observed misclassification rate compare to that expected by chance? As one means of evaluating the effectiveness of the discrimination, the observed classification rate was compared to that expected by chance alone (Norusis 1993b:15; Tabachnick & Fidell 1989:544). The accuracy of the discriminant analysis classification for individual groups and overall far exceeds that expected by chance alone (Table 7.2.1.9). This is also true for the reduced Australian classification rate arrived at by the Jackknife method.

7.2.3 SUMMARY: 6 GROUPS DISCRIMINANT ANALYSIS

The following conclusions are reached from the results of discrimination of 6 modern population groups using 17 temporal variables:

(i) The 17 temporal variables are able to discriminate Australians and the other 5 modern population groups. The observed classification rate overall and for each group far exceeds that expected by chance.

(ii) The Australian group is not the one most effectively discriminated by temporal variables. Andamanese have a higher classification accuracy (94.0%) and the Eskimo discriminant score distribution is the most distinct. The observed classification rate of Australians is 88.2% and their separation from other groups is evident in plots of discriminant function 1, 2 and 3 centroids, though not as extreme as that of Eskimos. Poundbury and Chinese groups, with classification accuracy of 56.0% and 76.0% respectively, are

the groups least successfully discriminated by temporal variables.

The Australian classification rate is reduced to 79% after adjustment is made for bias resulting from inclusion of classified cases in the construction of the discriminant function. (Such adjustment was not investigated for the other groups.)

(iii) The single function which best discriminates the Australians is Function 3. It accounts for 15% of the between-groups variance. The main predictors associated with function 3 are mastoid angle, length and depth and glenoid fossa medial/lateral width.

(iv) The four temporal variables which show the greatest difference in group means are tympanic plate lateral rim thickness, temporal squamous height, tympanic plate height and mastoid width. Tympanic rim thickness contributes most to the discrimination of the groups and is the most important predictor on the first function which accounts for 42.6% of the between-groups variance; it is very effective in separating the Eskimos from all other groups. The other variables are the 3 main predictors on function 2. These 4 variables, in combination with Function 3 and associated variables (mastoid angle, length and depth and glenoid fossa medial/lateral length) contribute to the separation of Australians from the other 5 groups.

Combining these results, Australians can be characterised by a mastoid process which is long, deep, narrow, and acutely inclined, a wide glenoid fossa, a low temporal squamous and a low tympanic plate. Their thick tympanic plate and large glenoid fossa ant./post. length distinguish them to some extent from all but the Eskimos.

(v) Of all groups, the Chinese are least like Australians in temporal features. The greatest contrast is in the Chinese higher and thinner-rimmed tympanic plate, higher temporal squamous and more vertically inclined mastoid process.

(vi) Of the 6 groups, Chinese and Poundbury are most alike in temporal features. They are least able to be discriminated by mastoid dimensions and orientation, glenoid fossa dimensions, temporal squamous height and tympanic plate height. They differ most in tympanic plate rim thickness.

7.2.4 RESULTS AND DISCUSSION:11 GROUPS DISCRIMINANT ANALYSIS

(Tables 7.2.2.1-8, Figs.7.2.2.1-10)

Inclusion of 11 groups in the discriminant analysis based on 17 temporal variables yields 10 discriminant functions (Table 7.2.2.1). The first four functions together account for 82.5% of the between-groups variability, and each has eigenvalue >.40, implying reliable discrimination (Hedderson 1991:146). Wilks' Lambda and associated Chi-square values and degrees of freedom show that the first 7 discriminant functions are reliable; the significance level associated with each of these functions (p=.0000) indicates that all 7 contribute substantially to group differences though after function$ 4, single functions account for little of the between groups variance (< 7%). The last 3 functions do not contribute substantially to group separation and represent random variation only.

Which discriminant function(s) and predictors identify Australians and other groups?

According to the group means of discriminant function scores, function 4 is the only single function which distinguishes Australians from the other 10 groups (Table 7.2.2.3). This function accounts for only 12.0% of the between groups variance, but is a reliable discriminant function (Chi-square (78) =306.2, p=.0000, Table 7.2.2.1). Mastoid process length, depth and orientation and petrous sagittal angle are the predictors with their maximum loading on function 4, as shown by pooled-within-groups correlation coefficients between predictors and functions (Table 7.2.2.2).

The predictors which distinguish the Australians in the 6 groups analysis were the same 3 mastoid variables, but the fourth predictor in this analysis is the petrous angle rather than glenoid fossa width. The 2 variables found in factor analysis to separate the Australians (mastoid angle and length) are among the distinguishing discriminant predictors.

Comparison of the absolute mean values for the four predictors on function 4 shows that of the 11 population groups, Australians have the second most acute angled mastoid (Bushman mean is smaller), the second smallest petrous

TABLE 7.2.2.1

11 GROUPS, 17 TEMPORAL VARIABLES, DISCRIMINANT ANALYSIS OF VARIANCE.

Function	Eigenvalue	% of Variance	Canonical Correlation
1	1.49	33.1	.77
2	1.07	23.8	.72
3	0.61	13.6	.62
4	0.54	12.0	.59
5	0.30	6.7	.48
6	0.23	5.0	.43
7	0.12	2.6	.32
8	0.08	1.7	.27
9	0.04	0.9	.20
10	0.02	0.5	.15

After Function	Wilks'Lambda	Chisquare	DF	Significance
0	.038	1397.4	170	.0000
1	.095	1007.3	144	.0000
2	.197	695.6	120	.0000
3	.318	490.9	98	.0000
4	.489	306.2	78	.0000
5	.637	192.7	60	.0000
6	.715	106.1	44	.0000
7	.842	59.1	30	.0012
8	.912	27.2	18	.0752
9	.973	9.6	8	.2932

TABLE 7.2.2.2

11 GROUPS, 17 TEMPORAL PREDICTORS, STRUCTURE MATRIX.

Pooled-within-groups correlations between discriminant variables and the first 5 of 10 canonical discriminant functions.
Values recorded are each variable's maximum loading* and other loadings >.300 (Tabachnick & Fidell 1989:539).

VARIABLE	FUNC 1	FUNC 2	FUNC 3	FUNC 4	FUNC 5
QTTHK	.737*		.326		
QGAP	.430*			-.325	
TSQH	.319	.558*			
LMPW		.554*		-.407	
QTPH		.536*	-.314		
TIND			.470*		
PLL			-.412*		
MPL		.335		-.606*	
PANGS				.455*	-.365
MANG				.404*	.319
MPD				-.325*	
QTPL					.498*
EANG					
BANT					
ATANGS	.306		-.353		
QGML		.309		-.415	

TABLE 7.2.2.3 11 GROUPS, 17 TEMPORAL PREDICTORS, GROUP MEANS OF FIRST 5 of 10 DISCRIMINANT FUNCTION SCORES.

GROUP	FUNC 1	FUNC 2	FUNC 3	FUNC 4	FUNC 5
AND	-1.29	-.86	.86	.98	.04
AUS	.67	-.92	.21	-1.20	-.19
BUS	-1.18	-1.06	-1.05	.42	-.74
CHI	-.88	1.89	-.15	.06	-.04
ESK	2.76	.23	-.45	.92	-.16
FUE	.80	1.35	1.29	-.61	1.53
GAB	-.64	-.67	-1.35	-.00	1.02
NEW	-.18	-.05	.78	-.11	-.04
POU	-.39	1.31	-.09	-.31	-.41
TAS	.44	-1.22	1.72	1.25	.24
VED	-1.10	-.50	-.77	.02	-.99

TABLE 7.2.2.4

11 groups, GROUP MEANS.
TEMPORAL VARIABLES ON DISCRIMINANT FUNCTIONS 1, 2, & 4.

GROUP	MANG	MPD	MPL	PANGS	QTTHK	QGAP	TSQH	QTPH	LMPW
And	73.20	11.27	27.53	46.67	1.196	3.990	41.32	3.897	1.218
Aus	64.52	12.88	32.52	43.63	1.758	4.212	43.45	4.010	1.269
Bus	64.18	11.25	28.04	43.88	1.404	3.958	39.24	4.042	1.246
Chi	70.22	12.68	32.39	46.80	1.492	4.151	48.42	4.327	1.340
Esk	67.33	12.31	29.81	48.33	2.144	4.265	49.78	4.122	1.246
Fue	68.78	13.52	34.18	44.72	1.647	4.374	47.24	4.169	1.384
Gab	69.66	10.81	29.73	42.34	1.505	4.068	43.88	4.143	1.250
New	67.69	12.98	30.81	45.37	1.470	4.202	45.64	4.088	1.287
Pou	66.85	12.74	33.41	46.84	1.612	4.160	47.05	4.234	1.346
Tas	69.91	11.39	24.63	49.00	1.469	4.178	39.19	3.849	1.224
Ved	68.36	11.41	29.10	45.83	1.575	3.948	42.70	4.004	1.261
Total	68.10	12.22	30.74	45.57	1.596	4.146	45.04	4.098	1.279

TABLE 7.2.2.5

11 groups, CORRELATION COEFFICIENTS
for TEMPORAL VARIABLES on DISCRIMINANT FUNCTIONS 1,2,4.

	MANG	MPD	MPL	PANGS	QTTHK	TSQH	QTPH
MANG	1.000						
MPD	-.133**	1.000					
MPL	-.350***	.600***	1.000				
PANGS	-.035	.002	-.069	1.000			
QTTHK					1.000		
QGAP					.384***		
TSQH						1.000	
QTPH						.293***	1.000
LMPW						.379***	.354***

* p < .05 ** p < .01 *** p < .001 (2-tailed significance)

sagittal angle (Gabon mean is smaller), the third longest mastoid process (Fuegian and Poundbury means are greater) and the third deepest mastoid process (Fuegian and New Britain means are greater) (Table 7.2.2.4). From Pearson correlation coefficients, petrous sagittal angle is not significantly correlated with any of the 3 mastoid predictors; correlations between the 3 mastoid predictors are all significant at $p<.001$ except mastoid angle with mastoid depth which is significant at $p<.01$ (Table 7.2.2.5).

As in the analysis involving 6 groups, the first function most effectively discriminates the Eskimos and is most strongly associated with tympanic plate lateral rim thickness and to less extent, glenoid fossa anterior/posterior length. In this analysis, function 1 accounts for 33.1% of the total between-groups variability (Table 7.2.2.1, 2 & 3). Tympanic rim thickness and glenoid fossa ant./post. length are the two predictors with the greatest between-groups variance (Table 7.2.1.1). Comparison of group means shows that Eskimos have the greatest glenoid fossa dimension and by far the thickest tympanic rim even when all 11 groups are considered; Australians have the next highest means for both variables (Table 7.2.2.4). The correlation between the two variables is moderate ($r=.384$, $p<.001$, Table 7.2.2.5).

Temporal squamous height, mastoid width and tympanic plate height are the variables with their maximum loading on function 2, which accounts for 23.8% of the between groups variance (Table 7.2.2.1). Correlations between the 3 variables are all moderate and significant at $p<.001$ (Table 7.2.2.5). With the addition of New Britain and the 4 small groups, Australian mean values in these variables are merely intermediate.

Distribution of discriminant scores and of group centroids are considered in scatter plots of Function 1 and 2, Function 1 and 4 and Function 2 and 4, (Figs.7.2.2.1-10).

FUNCTION 2 VS.FUNCTION 1. (Figs.7.2.2.1 & 2). With increase in the number of groups, overlapping of discriminant score distributions also increases. As in the 6 groups analysis , the distributions of Eskimos, and less clearly of Australians, are the most distinct but none are completely

Fig.7.2.2.1.Discriminant Fn. 1& 2 Scores

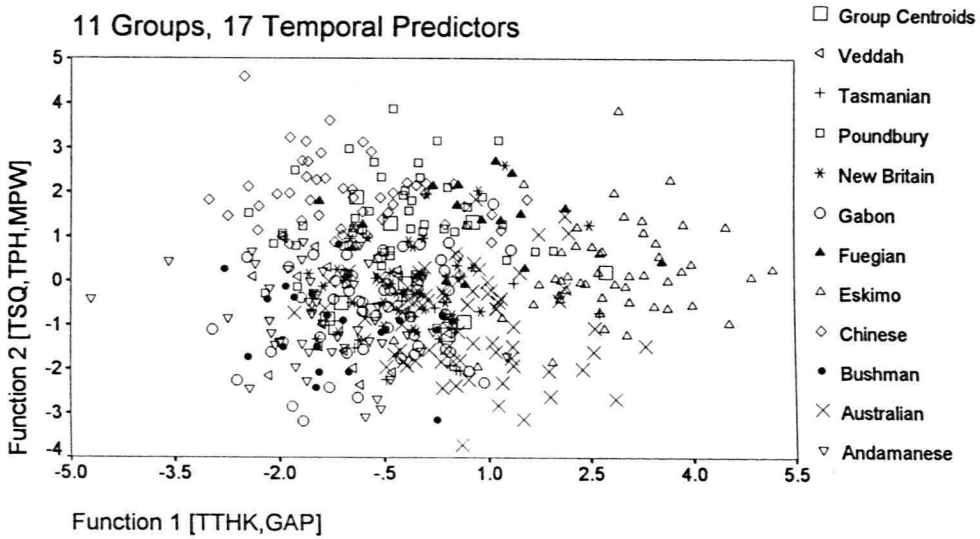


Fig.7.2.2.3. Discriminant Fn. 1& 4 Scores

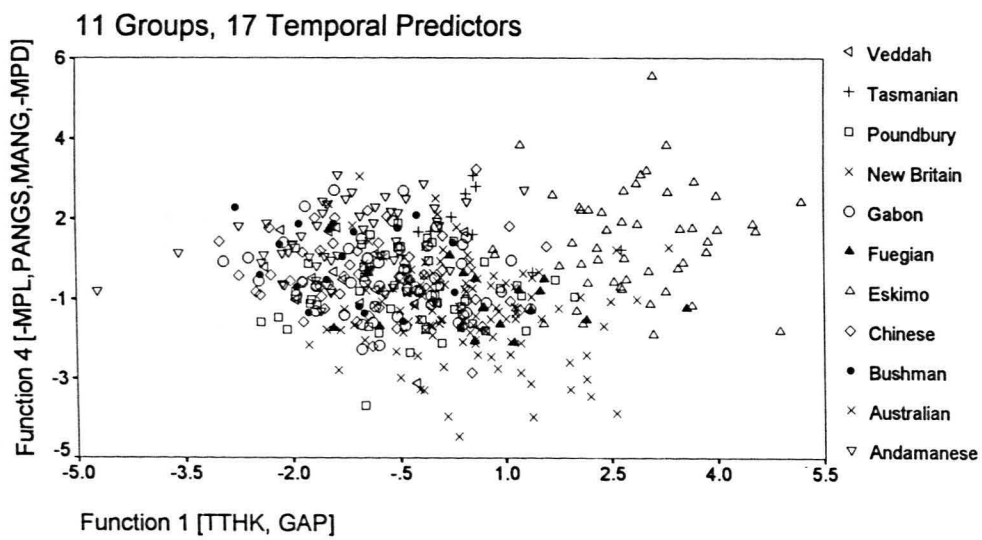


Fig.7.2.2.2. Group means of Discriminant Scores

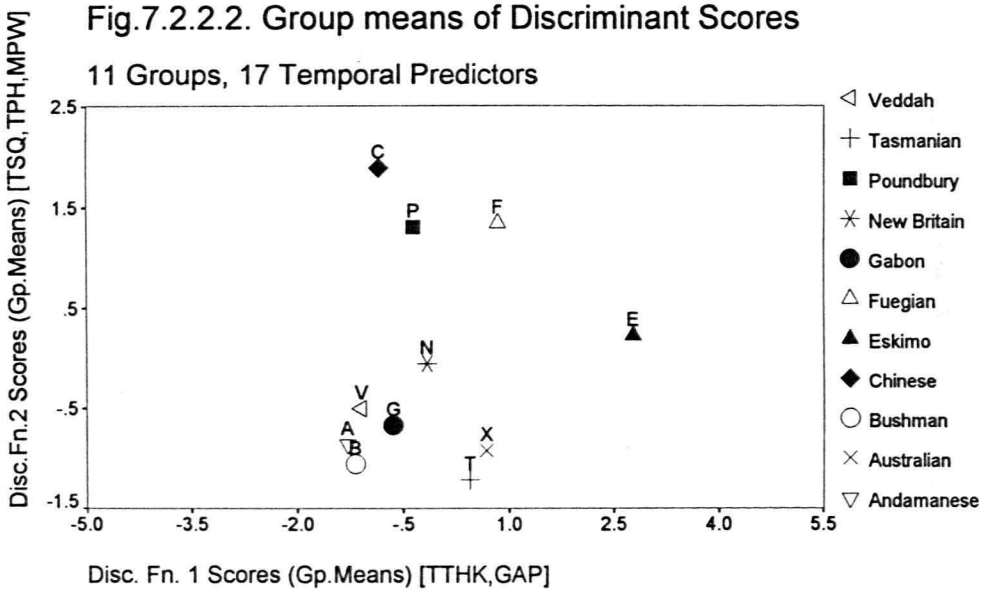


Fig.7.2.2.4. Group means of Discriminant Scores

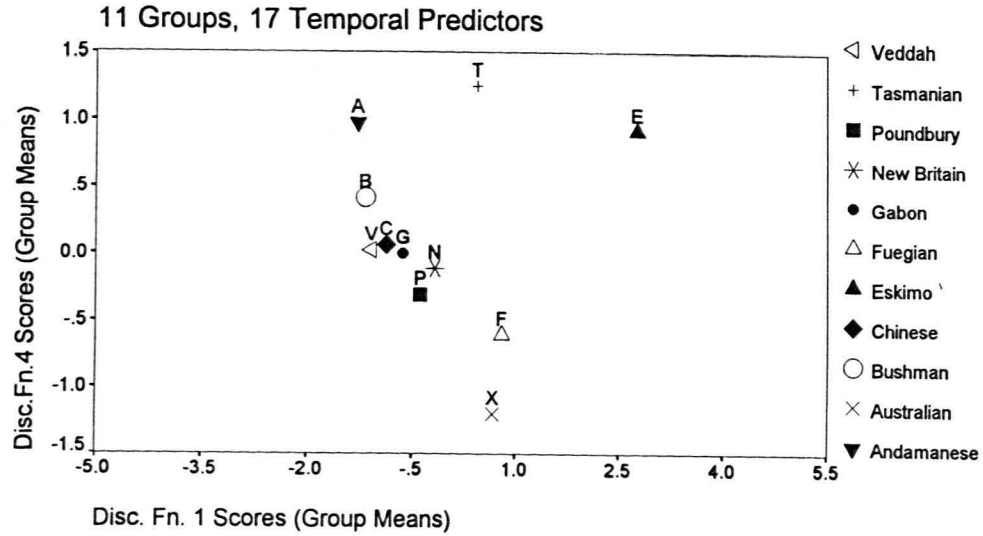


Fig.7.2.2.5.Discriminant Fn. 2& 4 Scores

11 Groups, 17 Temporal Predictors

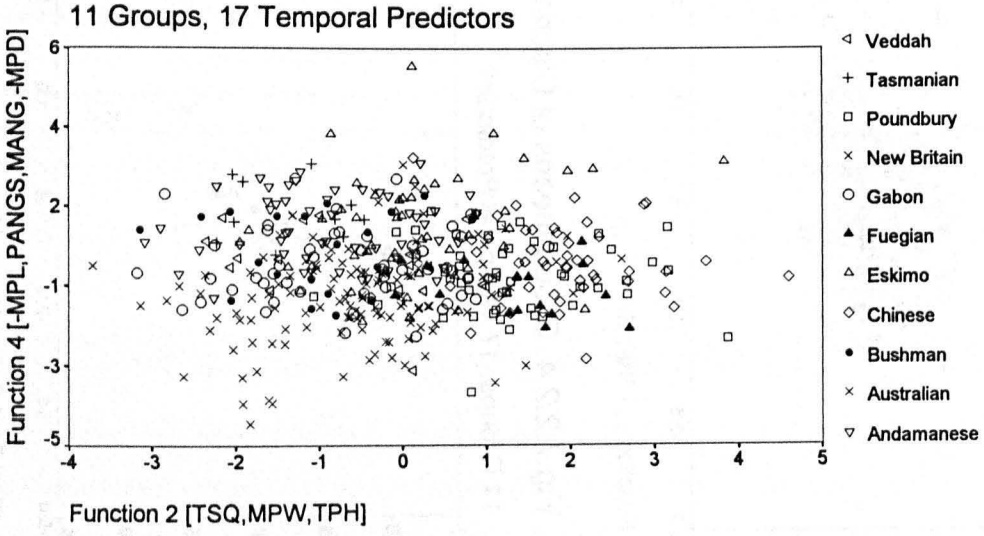
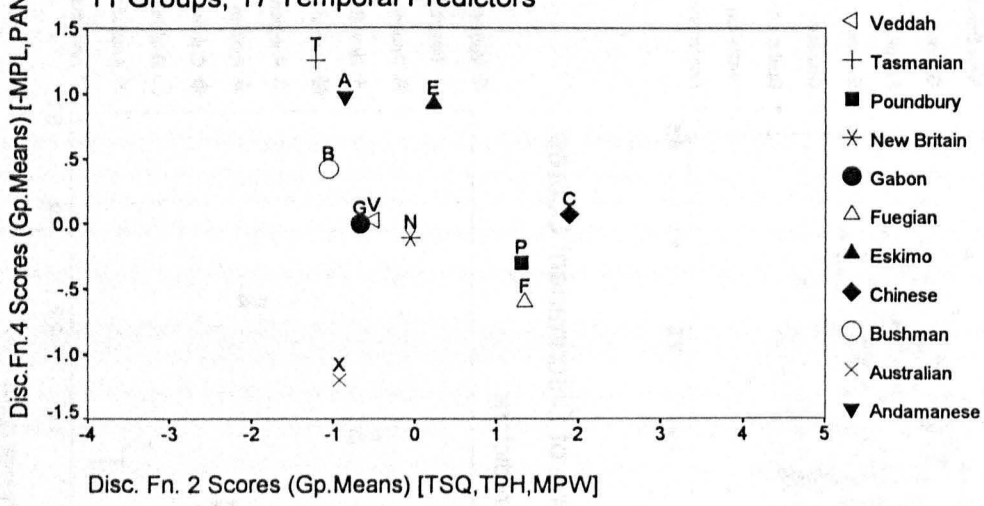


Fig.7.2.2.6. Group Means of Discriminant Scores

11 Groups, 17 Temporal Predictors

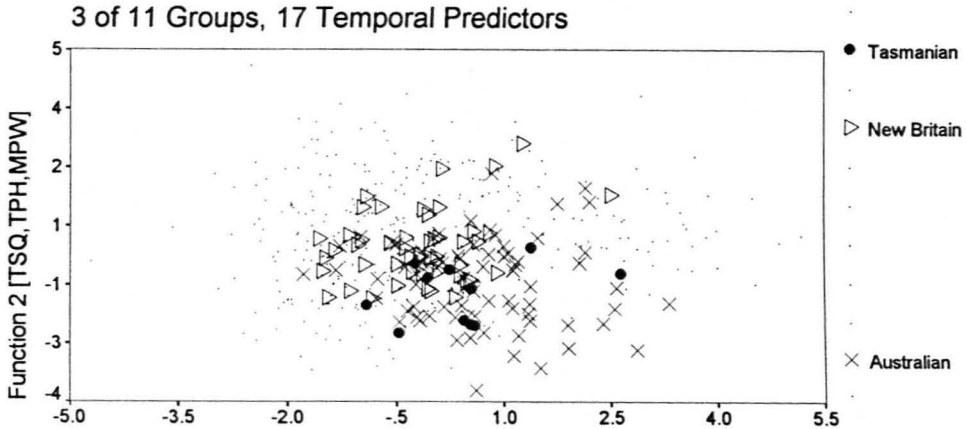


separate from all others (Fig.7.2.2.1). The group centroids plot shows the groups divided into three (Fig.7.2.2.2). Function 1 separates the Eskimos from all other groups, and function 2 divides Chinese, Poundbury and Fuegian (with a combination of high temporal squamous and tympanic plate and wide mastoid process) from Australian, New Britain, Tasmanian, Veddah, Andamanese and 2 African groups (low temporal squamous,low tympanic plate and narrow mastoid process).

FUNCTION 4 VS.FUNCTION 1. (Figs.7.2.2.3 & 4). When function 1 discriminant scores are plotted against those of function 4, function 1 distinguishes the Eskimo distribution from others, and function 4 partially distinguishes the Australian distribution (Fig.7.2.2.3). The group centroid plot shows the main effect more clearly. The sagitally inclined petrous, and acute angled, long, deep mastoid of Australians tends to separate them from all others, even with the inclusion in the analysis of 5 more groups. The Tasmanian centroid is at the opposite extreme of the distribution, reflecting how different the Tasmanians are to the Australians in mastoid size and orientation and petrous pyramid orientation. The Tasmanians have the shortest and second most vertically inclined mastoid and the most coronally oriented petrous, which is the opposite trend to that of Australians (Table 7.2.2.4).

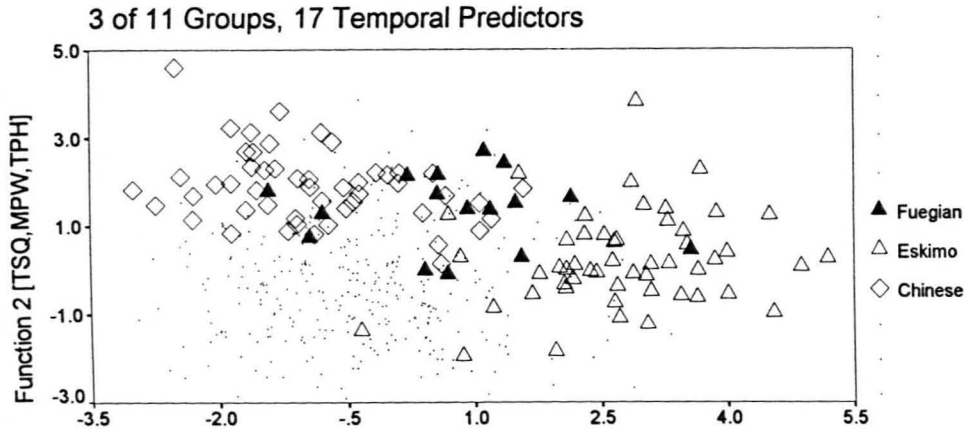
FUNCTION 4 VS.FUNCTION 2. (Figs.7.2.2.5 & 6). Without the influence of function 1, the Eskimo distribution is no longer distinguishable from the total modern sample distribution, but the Australian distribution is a little better distinguished with the combination of function 2 with function 4 (Fig.7.2.2.5). The Australian centroid is moderately well separated from all others (Fig.7.2.2.6). This reflects not just the long, deep and acutely angled mastoid and sagitally inclined petrous of Australians, but also their low tympanic plate low temporal squamous and narrow mastoid (Table 7.2.2.4). Chinese, Fuegian and Poundbury are grouped together, reflecting their common tendency to have a high temporal squamous, high tympanic plate and a wide mastoid process (function 2 predictors).

Fig.7.2.2.7.Australo-Melanesian Discriminant Scores



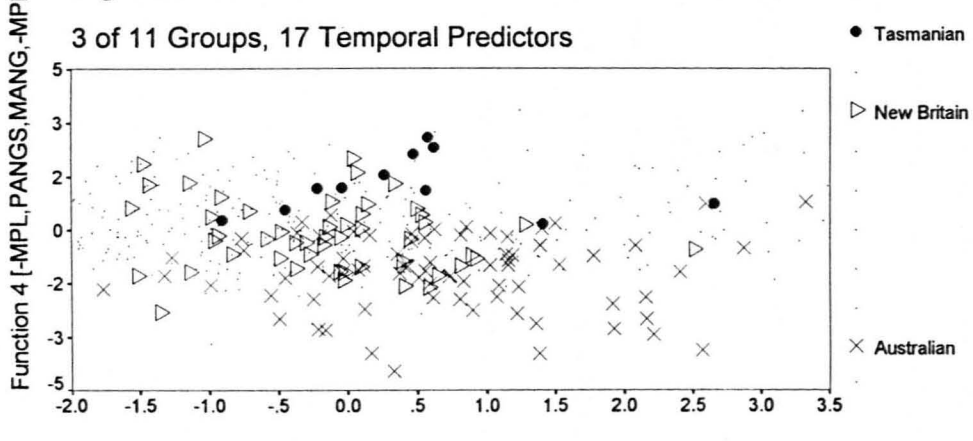
The 3 Melanesian distributions closely overlap.

Fig.7.2.2.9. Chinese, Fuegian & Eskimo Discriminant Scores



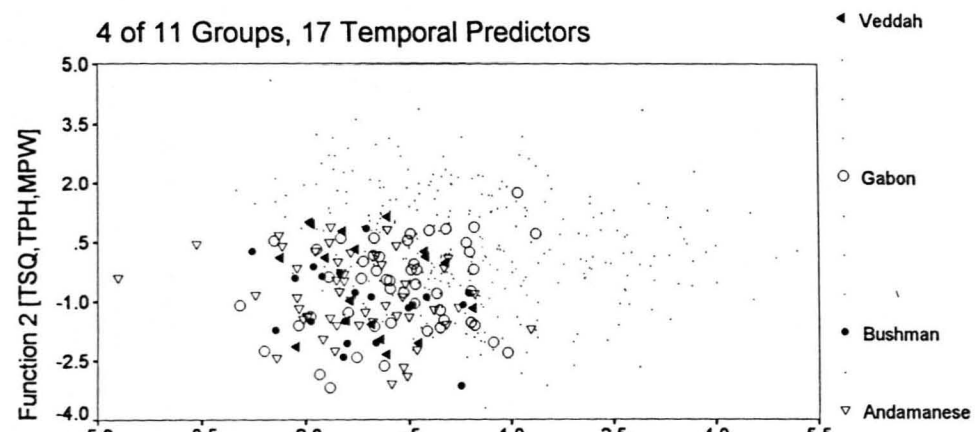
Chi. & Esk. distributions are distinct; Fueg.distribution overlaps both.

Fig.7.2.2.8.Australo-Melanesian Discriminant Scores



Fn.4 partially separates the 3 Melanesian groups; the Australian distribution is the most extreme, Tasmanian the most intermediate.

Fig.7.2.2.10.African, Andamanese & Veddah Disc.Scores



Gabon, Bushman,Gabon & Andamanese distributions closely overlap.

AUSTRALO-MELANESIAN DISTRIBUTIONS (Figs.7.2.2.7 & 8)
Compared to the total distribution, Australian, New Britain and Tasmanian function 1 and 2 discriminant score distributions closely overlap (Fig.7.2.2.7). But the New Britain scores tend to be at the extreme of the Australian distribution corresponding to crania with thinner tympanic rims; the absolute mean values for this variable confirm that the two groups differ considerably in this feature (Table 7.2.2.4).

When the plot of discriminant scores of function 4 and 1 is considered, Australians and Tasmanians are almost distinct, reflecting the contrast in their mastoid and petrous features (function 4 predictors) pointed out previously in the discussion of Figs.7.2.2.3 & 4.

CHINESE, FUEGIAN AND ESKIMO DISTRIBUTIONS (Figs.7.2.2.9)
As in the 6 groups analysis, Chinese and Eskimo distributions are almost distinct from each other, but with Fuegians also in the analysis, both distributions are overlapped by that of Fuegians. The separation of Chinese and Eskimo groups is largely on the basis of very thin vs. very thick tympanic rim; the Fuegian tympanic rim is less extreme in thickness than either Chinese or Eskimo (Table 7.2.2.4).

AFRICAN AND RELATED DISTRIBUTIONS (Figs.7.2.2.10).
Gabon, Bushman, Veddah and Andamanese show quite a tight overlap of discriminant score distributions in the plot of function 1 against function 2. This implies similarity in temporal features particularly in the 5 predictors associated with function 1 and 2 (tympanic rim thickness, glenoid fossa ant./post. length, temporal squamous height, mastoid width and tympanic plate height).

7.2.5 ACCURACY OF THE ANALYSIS

1. How accurately can the Australians and other 10 groups be classified on the basis of discrimination by temporal variables?

For each of the 6 large sample, geographically distinct groups, the percentage of correctly classified cases was reduced by between 3.8% and 14% by the inclusion of 5 additional groups in the discriminant analysis (Table 7.2.2.6). The overall classification rate is 11.9% less accurate, and that of Australians decreases from 88.2% to 75%. Australian, Gabon and Andamanese are the groups whose classification accuracy is most reduced (by 12-14%), while that of Eskimo, Poundbury and Chinese groups is least altered by the introduction of the additional groups (3.8-8%).

The similarity of Australian and New Britain temporal features is indicated by the fact that most of the misclassified Australians are grouped with New Britain (10.5%), and most of the New Britain misclassifications are grouped with Australians (18%). Misclassified Tasmanian cases are grouped with New Britain rather than Australians.

As in the 6 groups analysis, the similarity in temporal features between Poundbury and Chinese is reiterated in that most of the misclassified Poundbury are grouped with Chinese (22%), and most of the misclassified Chinese are grouped with Poundbury (24%). Gabon misclassifications are spread widely, but most are with Australians, New Britain, Andamanese, Bushman and Veddah rather than with Chinese, Eskimo or Fuegian.

The groups least effectively classified are Poundbury, Veddah and New Britain (50%, 50% and 54% respectively). The central position of the distributions relative to the total distribution suggests that these groups have generalised features.

2. How well does the observed misclassification rate compare to that expected by chance?

Despite the reduction in the percentage of correct classifications with an increased number of groups, the observed classification rate in the 11 groups discrimination analysis still exceeds by far the rate expected by chance (Table 7.2.2.7).

TABLE 7.2.2.6

11 GROUPS, 17 TEMPORAL PREDICTORS, OBSERVED CLASSIFICATION RESULTS.

Group	No.of Cases	PREDICTED GROUP MEMBERSHIP										
		AND	AUS	BUS	CHI	ESK	FUE	GAB	NEW	POU	TAS	VED
AND	50	40	1	1	0	0	0	3	2	0	1	2
		80.0%	2.0%	2.0%	.0%	.0%	.0%	6.0%	4.0%	.0%	2.0%	4.0%
AUS	76	1	63	3	0	2	1	1	8	3	0	0
		1.3%	75.0%	3.9%	.0%	2.6%	1.3%	1.3%	10.5%	3.9%	.0%	.0%
BUS	20	2	2	14	1	0	0	0	1	0	0	0
		10.0%	10.0%	70.0%	5.0%	.0%	.0%	.0%	5.0%	.0%	.0%	.0%
CHI	50	0	0	0	34	1	0	0	2	12	0	1
		.0%	.0%	.0%	68.0%	2.0%	.0%	.0%	4.0%	24.0%	.0%	2.0%
ESK	52	0	3	0	0	43	1	1	1	1	1	1
		.0%	5.8%	.0%	.0%	82.7%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%
FUE	16	0	0	0	0	1	13	0	0	2	0	0
		.0%	.0%	.0%	.0%	6.3%	81.3%	.0%	.0%	12.5%	.0%	.0%
GAB	50	3	4	2	1	0	0	34	3	0	0	3
		6.0%	8.0%	4.0%	2.0%	.0%	.0%	68.0%	6.0%	.0%	.0%	6.0%
NEW	50	7	9	0	0	0	2	1	27	3	1	0
		14.0%	18.0%	.0%	.0%	.0%	4.0%	2.0%	54.0%	6.0%	2.0%	.0%
POU	50	2	1	0	11	1	0	2	4	25	0	0
		4.0%	2.0%	.0%	22.0%	2.0%	.0%	4.0%	8.0%	50.0%	.0%	.0%
TAS	11	0	0	0	0	0	0	0	2	0	9	0
		.0%	.0%	.0%	.0%	.0%	.0%	.0%	18.2%	.0%	81.8%	.0%
VED	18	1	0	1	2	0	0	1	1	3	0	9
		5.6%	.0%	5.6%	11.1%	.0%	.0%	5.6%	5.6%	16.7%	.0%	50.0%
TOTAL	443	TOTAL CORRECTLY CLASSIFIED								68.9%		

TABLE 7.2.2.7. 11 GROUPS, 17 TEMPORAL PREDICTORS, CORRECT CLASSIFICATIONS BY ANALYSIS COMPARED TO THAT EXPECTED BY CHANCE.

	And	Aus	Bus	Chi	Esk	Fue	Gab	New	Pou	Tas	Ved	TOTAL
No in GROUP	50	76	20	50	52	16	50	50	50	11	18	443
ANALYSIS												
No.	40	57	14	34	43	13	34	27	25	9	9	305
%	80.0%	75.0%	70.0%	68.0%	82.7%	81.3%	68.0%	54.0%	50.0%	81.8%	50.0%	68.9%
CHANCE												
No.	5.6	13.0	.9	5.6	6.1	.6	5.6	5.6	5.6	.3	.7	49.6
%	11.3%	17.2%	4.5%	11.3%	11.7%	3.6%	11.3%	11.3%	11.3%	2.5%	4.1%	11.2%

7.2.6 SUMMARY: 11 GROUPS DISCRIMINATION ANALYSIS

(i) 11 modern population groups can be classified by means of 17 temporal variables with an overall accuracy of 68.9%. Though considerably less than the accuracy achieved when the analysis involved only 6 population groups which are more geographically distinct, yet it far exceeds the classification rate expected by chance alone.

(ii) The 11 groups analysis resulted in the same pattern of relationships which emerged from the 6 groups analysis, as well as some additional findings.

(iii) Australians, with 75% correct classification accuracy, are among the groups most effectively discriminated by temporal features, but they are not more effectively discriminated than all other groups and cannot be said to be remarkably different to all other modern groups in temporal features.

(iv) From group means of discriminant function scores, function 4, accounting for only 12% of the between-groups variability, is the single function which best separates Australians from the other 10 groups. From function plots, it is clear that the combined effect of Function 2 with Function 4 enhances the Australian separation.

(v) As in the 6 groups analysis, the length, depth and angle of inclination of the mastoid process are 3 of the 4 predictors contributing most to the discrimination of the Australians. In this analysis the fourth predictor is petrous pyramid sagittal angle whereas in the 6 group analysis it was glenoid fossa width. This discriminant analysis characterises Australians as having a deep, long, acutely inclined mastoid, and a sagitally inclined petrous. Considering also the contribution of function 2 predictors, a low temporal squamous, low tympanic plate and narrow mastoid substantially enhances their discrimination.

(vi) Compared to other groups and according to the close overlap of their function 1 and 2 discriminant scores,

Australian, New Britain and Tasmanian groups have similar temporal features. Nevertheless, important differences exist between the 3 groups; the New Britain tympanic rim is considerably thinner than that of Australians. Tasmanians differ from Australians in having a short vertically inclined mastoid process and a coronally oriented petrous pyramid. However, the differences may not have been so noticeable or even existed if the Tasmanian sample had been larger (n=11). The inclusion of New Britain and Tasmanian crania in the 11 groups sample doubtless blurs the distinction of Australians from all other groups.

(vii) The similarity of Chinese and Poundbury temporal features and their dissimilarity to those of Australians is evident in this analysis as it was when only 6 groups were involved as it was in the analysis for 6 groups.

(viii) As in the 6 groups analysis, a marked separation of the Eskimos from all other groups is achieved largely through the first function based on tympanic plate lateral rim thickness and, less importantly, on glenoid fossa anterior/posterior length.

(ix) Fuegians form a link between Eskimo and Chinese groups in that the virtually distinct discriminant score distributions of Chinese and Eskimo are both overlapped by the Fuegian distribution.

(x) There is considerable overlap of discriminant score distributions of Gabon with Bushman, but also of these 2 African groups with Andamanese and Veddah. The implied similarity of their temporal features is repeated in the pattern of their misclassifications. Australian, Tasmanian and New Britain groups are closer to this African grouping rather than to the Chinese/Poundbury/Fuegian grouping, when the discriminant scores are based on the combined effect of function 1 and 2 temporal predictors (tympanic rim thickness, glenoid fossa ant./post. length, temporal squamous height, tympanic plate height, and mastoid process width).

7.3 EFFECTIVENESS OF TEMPORAL VARIABLES COMPARED TO NON-TEMPORAL VARIABLES IN DISCRIMINATING AUSTRALIANS AND OTHER MODERN GROUPS.

7.3.1 PURPOSE AND PROCEDURE

7.3.1.1 PURPOSE: It has been established that crania from modern population groups, including Australians, can be distinguished from one another to some extent on the basis of temporal features alone, But how effective are temporal variables in discriminating and classifying groups compared to non-temporal variables? To answer this question, results from discriminant analysis for 6 groups and for 11 groups are compared with results from equivalent analyses involving non-temporal variables.

7.3.1.2 PROCEDURE

Two sets (a & b) of non-temporal variables were analyzed and are listed in Table 7.3.1:

a) The 17 non-temporal variables used in the section in which the effect of size-adjustment on discrimination was investigated. The variable cranial length (GOL) had been excluded since it was found to have insufficient tolerance in the analyses involving size-adjustment.

b) This set includes cranial length since it does not fail the tolerance test if the variables are not adjusted for size, as is the case here. The other variables are the same except for lambda-inion/inion-opisthion ratio, the non-temporal variable with least between groups variance (Table 7.3.1), which is excluded in order that the total number of variables in the analysis remains at 17.

Direct discriminant analysis was applied to the 2 sets of variables (a) and b)), for 6 groups and for 11 groups. Prior probability was based on sample size and tolerance was set at .01. Though all variables passed the tolerance test, it was noted that the inclusion of cranial length is a border line decision since it has correlation coefficients $>.70$, $p < .001$ with three of the other non-temporal predictors, frontal and occipital arcs and biasterion breadth (Hedderson, 1991:148). The apparent importance of cranial length as a discriminator may reflect rather the redundancy of its inclusion with the other 3 predictors.

TABLE 7.3.1 NON-TEMPORAL VARIABLES used in 6 GROUPS DISCRIMINANT ANALYSIS

Wilks' Lambda (U-statistic) and univariate F-ratio with 5 and 322 degrees of freedom

Variable	Wilks' Lambda	F	Significance
ASB	.5934	44.1330	.0000
AUB	.5381	55.2871	.0000
BANG	.7592	20.4251	.0000
BBH	.8186	14.2672	.0000
ENØIN	.8093	15.1719	.0000
FANG	.8078	15.3241	.0000
FRA	.7551	20.8870	.0000
GOL	.4704	72.4934	.0000
LFMB	.8596	10.5159	.0000
LFML	.6722	31.4105	.0000
LOIX	.9475	3.5674	.0037
NLB	.5829	46.0877	.0000
OCA	.6490	34.8296	.0000
OCNINA	.7993	16.1661	.0000
PAA	.8392	12.3360	.0000
SPHO	.6199	39.4929	.0000
WCB	.7974	16.3664	.0000
XCB	.6321	37.4821	.0000

NON-TEMPORAL VARIABLES used in 11 GROUPS DISCRIMINANT ANALYSIS.

Wilks' Lambda (U-statistic) and univariate F-ratio with 10 and 432 degrees of freedom

Variable	Wilks' Lambda	F	Significance
ASB	.6057	28.1212	.0000
AUB	.4994	43.3092	.0000
BANG	.7516	14.2769	.0000
BBH	.7753	12.5234	.0000
ENØIN	.8306	8.8101	.0000
FANG	.8209	9.4250	.0000
FRA	.7658	13.2104	.0000
GOL	.5258	38.9604	.0000
LOIX	.9140	4.0663	.0000
LFMB	.8562	7.2546	.0000
LFML	.6971	18.7725	.0000
NLB	.6306	25.3061	.0000
OCA	.6772	20.5967	.0000
OCNINA	.7906	11.4430	.0000
PAA	.8334	8.6366	.0000
SPHO	.6551	22.7482	.0000
WCB	.7902	11.4732	.0000
XCB	.5773	31.6291	.0000

TABLE 7.3.2. GROUP MEANS

NON-TEMPORAL VARIABLES ON DISCRIMINANT FUNCTIONS 1. & 2.

GROUP	XCB	NLB	GOL	FRA	AUB	OCA
And	134.2	23.6	164.8	118.4	110.9	105.1
Aus	129.8	27.2	183.3	127.8	116.2	111.7
Chi	138.3	25.8	177.6	124.4	122.8	116.3
Esk	134.7	23.0	187.5	129.6	124.0	118.0
Gab	132.7	26.8	175.8	123.6	112.6	108.7
Pou	141.6	24.5	185.8	128.5	121.7	118.2
Bus	134.0	25.36	175.6	127.2	110.4	111.1
Fue	142.3	24.49	187.0	128.3	129.6	120.9
New	130.2	26.47	177.7	121.4	117.8	112.5
Tas	135.0	26.79	180.4	124.0	119.3	111.9
Ved	126.8	24.73	177.7	126.9	110.9	107.9

7.3.2 RESULTS

The Wilks' Lambda and F values (Table 7.3.1) indicate that the group means for all variables except one in the 6 groups analysis are significantly different (p=.0000); and for the exception, lambda-inion/inion-opisthion ratio, the difference is sufficient (p=.0037) for it to be included in the discriminant analysis (Norusis 1993b:4). The variables with greatest between-groups variance among 6 groups are cranial length, biauricular breadth and nasal width, and among 11 groups, cranial length, biauricular breadth and maximum parietal breadth.

7.3.2.1 6 GROUPS NON-TEMPORAL DISCRIMINATION ANALYSIS

Both sets of variables, a) and b), yield 5 discriminant functions, which are reliable (p =.0000). The first three functions together account for a) 83.3% and b) 84.1% of the between-groups variability.

When cranial length is not included (analysis a)), the single discriminant function which best separates Australians is function 2. It accounts for 29.0% of the between-groups variability and is most strongly associated with maximum parietal breadth and nasal width. According to absolute mean values, Australians have the smallest parietal breadth and the widest nasal aperture of the 6 groups (Table 7.3.2). There is no correlation between these 2 predictors at $p<.05$.

No plots of discriminant scores or of discriminant group means for function 1 and function 2 (Figs.7.3.1.1-4) show any group with a distribution or centroid completely distinct from all others. The group centroid plot of the first analysis, (Fig.7.3.1.2), indicates that Eskimos are the most different of the 6 groups, but not to the extent implied by discrimination based on temporal predictors; here they are distinguished by function 1 and its associated predictors, large biauricular breadth and long occipital arc. Chinese and Poundbury are indicated as being very similar as was the case with temporal predictors.

In the analysis of set b) variables, with cranial length included, Australians are most efficiently separated by function 1. It accounts for 37.4% of the between-groups variability and is most strongly associated with cranial length and frontal arc. The 2 variables are quite highly

Fig.7.3.1.1.Discriminant Fn. 1 & 2 Scores

6 Groups, 17 Non-Temporal Variables (no GOL)

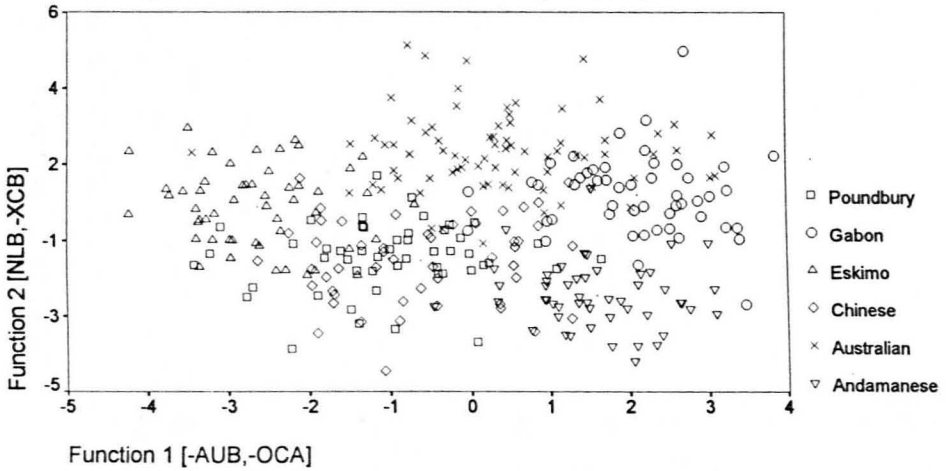


Fig.7.3.1.2 Group Means of Discriminant Scores

6 Groups, 17 Non-Temporal Variables (no GOL)

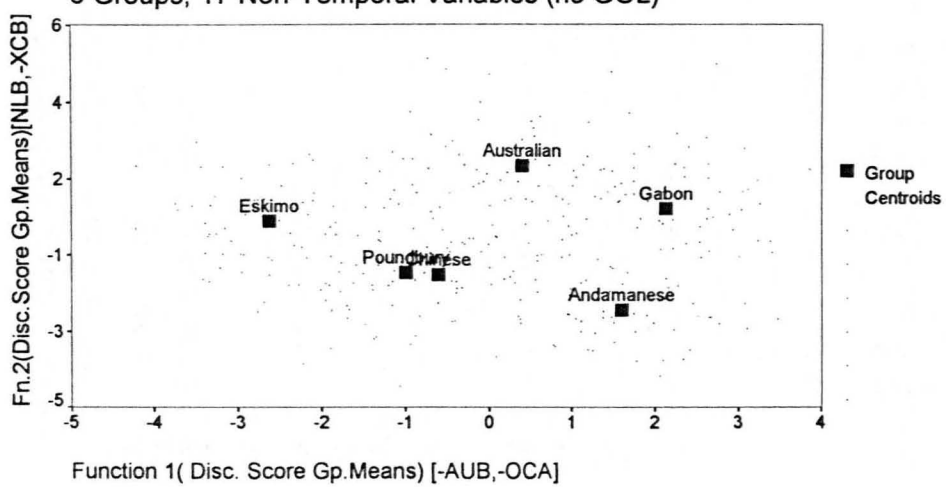


Fig.7.3.1.3.Discriminant Fn. 1 & 2 Scores

6 Groups, 17 Non-Temporal Variables (with GOL)

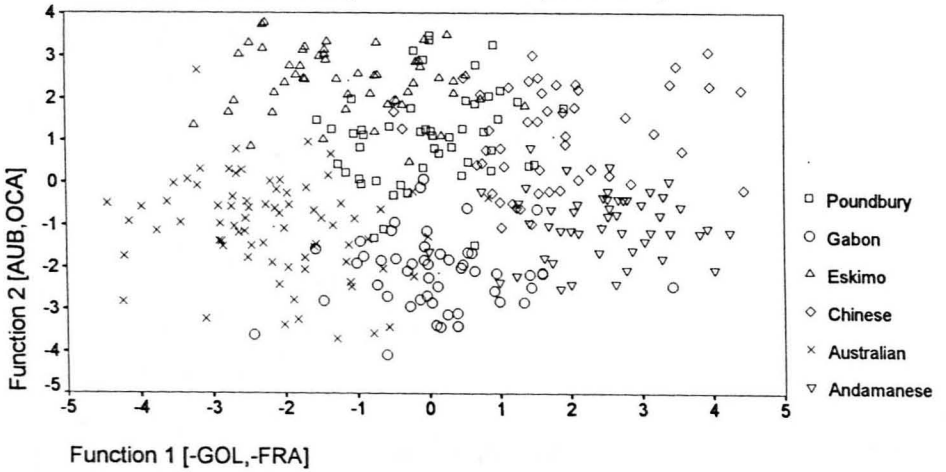


Fig.7.3.1.4.Group Means of Discriminant Scores

6 Groups, 17 Non-Temporal Variables (with GOL)

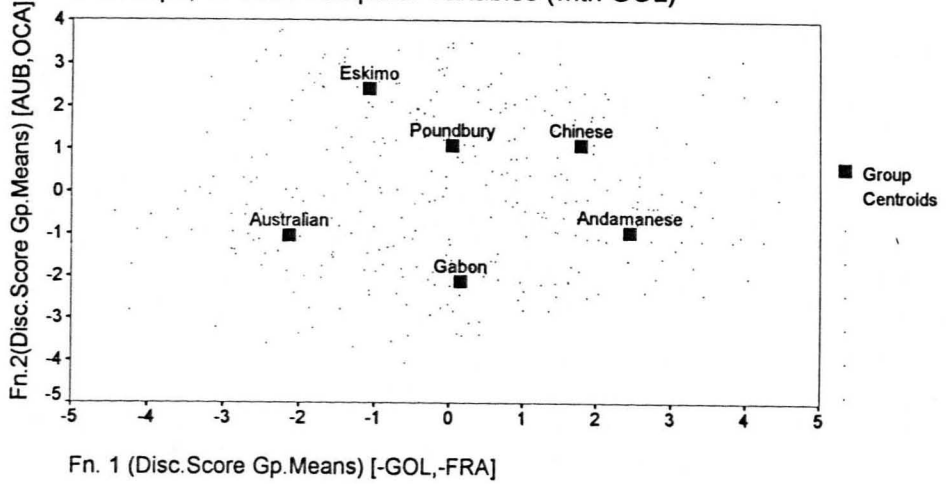


Fig.7.3.1.5.Discriminant Fn. 1 & 2 Scores

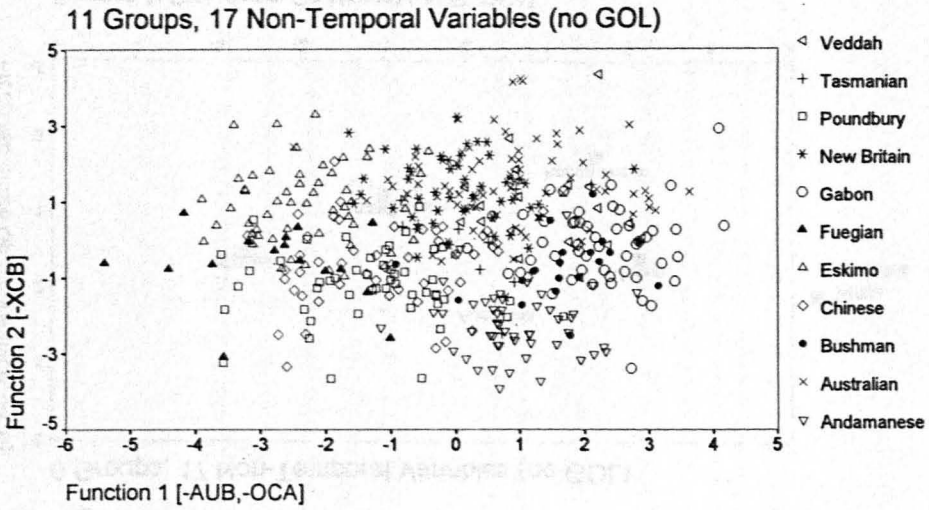


Fig.7.3.1.6.Group Means of Discriminant Scores

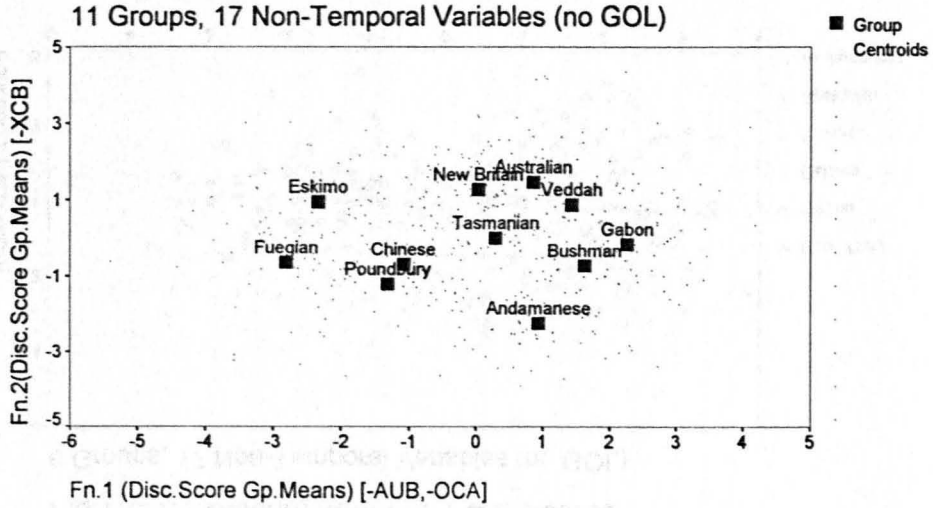


Fig.7.3.1.7.Discriminant Fn. 1 & 2 Scores

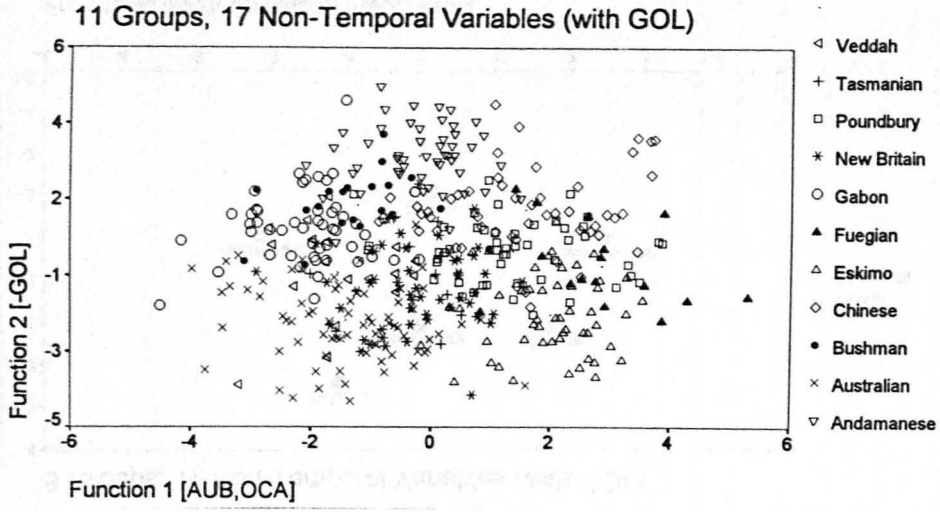
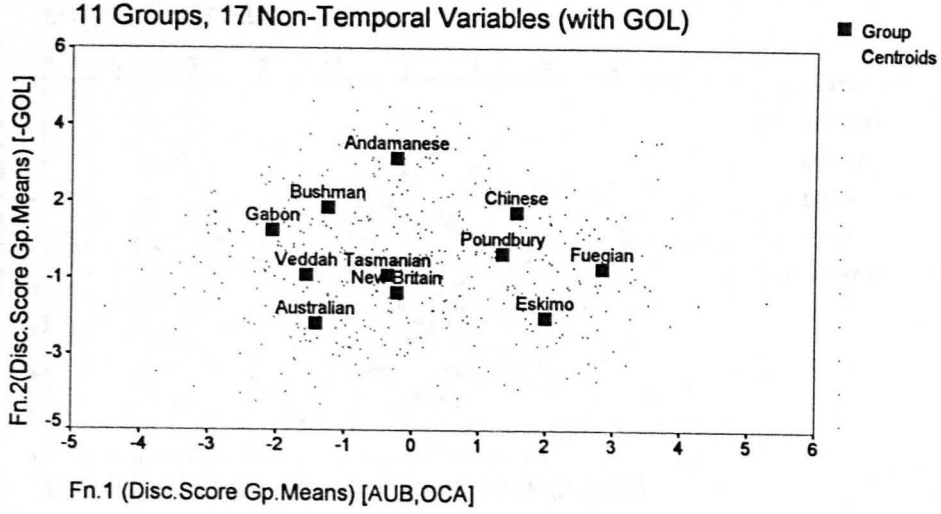


Fig.7.3.1.8.Group Means of Discriminant Scores



correlated (r=.747, p <.001). The inclusion of cranial length lessens the overlap of the Australian distribution with those of other groups (Fig.7.3.1.3), but Australian absolute mean values are no more than intermediate for any of the highest loading variables associated with either function 1 or 2 in analysis b); biauricular breadth and occipital arc are associated with function 2 (Table 7.3.2).

Improvement in discrimination by the inclusion of cranial length is quantitatively reflected by improvement in classification accuracy overall by 4.9% and for Australians by 3.9% (Table 7.3.3).

7.3.2.2 11 GROUPS NON-TEMPORAL DISCRIMINATION ANALYSIS

Of the 10 discriminant functions produced by each of the two analyses, a) and b), the first 8 are shown to be reliable by Wilks' Lambda and F values significant at p=.0000. The first 4 functions altogether account for a) 85.0% and b) 84.3% of the between groups variability.

Function 1 accounts for a) 36.3%, and b) 32.7% of the between-groups variability. In both analyses, biauricular breadth and occipital arc have their highest loading on function 1. Australian absolute means for biauricular breadth and occipital arc are no more than intermediate; the correlation between these two predictors is moderately strong (r=.544, p<.001).

With cranial length excluded in analysis a), the single discriminant function best separating the Australian group from all others is function 2; it is most strongly associated with maximum parietal breadth. Only Veddah have a smaller parietal breadth absolute mean than Australians (Table 7.3.2).

When cranial length is included (Analysis b)), the group means of discriminant scores indicate that no single function separates the Australians from all other groups, but in plotting function 1 and 2, the combined effect of the comparatively long and narrow cranium of Australians places their discriminant score distribution at one extreme of the full distribution (Fig.7.3.1.7).

As in the 6 groups analysis, the discriminant score plots for function 1 and 2 show slightly better separation of the Australian distribution by inclusion of cranial length as a predictor (Figs.7.3.1.5 & 7). In a number of ways, the

TABLE 7:3.3

EFFECTIVENESS OF TEMPORAL VARIABLES COMPARED TO NON-TEMPORAL VARIABLES AS PREDICTORS IN CLASSIFICATION OF 6 POPULATION GROUPS

* based on group means of discriminant scores.

	17 TEMPORAL VARIABLES	17 NON-TEMPORAL VARIABLES [1]	[2]	9 TEMPORAL & 8 NON-TEMPORAL VARIABLES
% CORRECT PREDICTION for Australians	88.2%	89.5%	93.4%	94.7%
for all 6 groups	80.8%	88.1%	93.0%	91.2%
Discriminant Function & its highest correlated variables which best* separate Australians. (Cor.coeffs.quoted)	D. Fn. 3 MPL -.56 MANG .45 GML -.45 MPD -.42	D. Fn. 2 XCB -.40 NLB .40	D. Fn. 1 GOL -.50 FRA -.28	D. Fn. 2 NLB -.43 PANGS .30 TSQH .30

TABLE 7.3.4

EFFECTIVENESS OF TEMPORAL VARIABLES COMPARED TO NON-TEMPORAL VARIABLES AS PREDICTORS IN CLASSIFICATION OF 11 POPULATION GROUPS

* based on group means of discriminant scores.

	17 TEMPORAL VARIABLES	17 NON-TEMPORAL VARIABLES [1]	[2]	9 TEMPORAL & 8 NON-TEMPORAL VARIABLES
% CORRECT PREDICTION for Australians	75.0%	80.3%	86.8%	92.1%
for all 11 groups	68.9%	78.6%	82.4%	83.1%
Discriminant Function and its highest correlated variables which best* separate Australians. (Cor.coeffs.quoted)	D. Fn. 4 MPL -.61 PANGS .46 MANG .40 MPD -.33	D. Fn. 2 XCB -.44	D. Fn. 2 GOL -.54	D. Fn. 2 (XCB .44) (NLB -.33)

centroid plots reveal a similar distribution pattern as in the equivalent analysis based on temporal predictors. For example, Chinese and Poundbury are paired, Fuegian distribution is between and overlapping Chinese and Eskimos distributions, and the total distribution can be regarded as divided in two, a Chinese-Poundbury-Fuegian-Eskimo grouping and Australia and African groups with the rest, though the Andamanese position is ambivalent (Figs.7.3.1.6 & 8). The division is principally on the basis of function 1 and associated variables, Chinese, Poundbury, Fuegian, and Eskimo groups having the largest means for both biauricular breadth and occipital arc.

The inclusion of cranial length improves the classification accuracy more for Australians (6.5% increase) than overall (3.7% increase) (Table 7.3.4).

7.3.3 DISCUSSION

1. How do these discriminant results based on non-temporal variables compare with those based on temporal variables?

Results from the equivalent discriminant analyses based on temporal predictors are also recorded in Tables 7.3.3 & 4. Both analyses a) and b) of non-temporal variables achieve a higher percentage of classification accuracy overall and for Australians in particular than did the temporal-based analyses.

When 6 groups are involved, there is an increase in accuracy
for Australians of a) 1.3% and b) 5.2%,
and overall of a) 7.3% and b) 12.2%.

When 11 groups are involved, there is an increase in accuracy
for Australians of a) 5.3% and b) 11.8%,
and overall of a) 9.7% and b) 13.4%.

These results have the following implications:

Although Australian crania are more effectively classified by non-temporal rather than temporal variables, the difference is slight when only 6 groups are involved.

The improvement in classification accuracy by use of non-temporal rather than temporal predictors is greater for groups overall than it is for Australians. That is, Australians are more effectively discriminated by temporal variables than modern groups in general; this does not necessarily mean Australians are the group most effectively discriminated by temporal predictors.

Other combinations of 17 non-temporal variables were also analyzed with 6 groups involved and with 11 groups involved. None resulted in a higher discrimination accuracy than that reached on the basis of the 17 non-temporal predictors in analysis b), but a number achieved less accuracy than the analysis based on 17 temporal variables. This suggests caution should be exercised in making generalizations about the discriminating effectiveness of temporal variables compared with non-temporal variables.

However, on the basis of the particular variables and population samples considered in this study it can be concluded:

Discrimination of 6 groups in general is improved when non-temporal rather than temporal variables are involved, but the increase in classification accuracy for Australians in particular is only slight, especially if cranial length is not one of the non-temporal variables.

Discrimination of 11 groups, both overall and for Australians in particular, is substantially improved by use of non-temporal variables rather than temporal variables. This suggests that Australians compared to groups such as New Britain and Tasmanian, differ more in non-temporal features than in temporal features.

2. Does a combination of temporal and non-temporal predictors yield a more effective Discrimination?

A total of 17 variables (9 temporal and 8 non-temporal variables), were submitted for discriminant analysis involving

1] 6 groups and 2] 11 groups.

The variables were taken from those which, according to the U-statistic, have the greatest between-groups variance (Tables 7.2.1.1 & 7.3.1.). The 9 temporal variables also included the variables associated with the functions which had best separated Australians in the analyses of temporal predictors.

In the 6 groups analysis, all 4 functions are reliable (p=.0000) and the first 3 account for 87.8% of the between-groups variability. In the 11 groups analysis all but the last (10th.) function are indicated as contributing significantly (p =.0000) to the discrimination, and the first 3 functions account for 84.3% of the between-groups variability.

In both the 6 groups and 11 groups analyses, the single

function which most effectively separates the Australians is function 2. This function is most strongly associated with nasal width, petrous sagittal angle and temporal squamous height (1 non-temporal, 2 temporal variables) in the 6 groups analysis, and with maximum parietal breadth and nasal width (2 non-temporal variables) in the 11 groups analysis. This is consistent with the earlier finding that temporal variables are less effective in separating Australians from 11 groups than from 6 groups, that Australians differ more in non-temporal than temporal features from groups such as New Britain Veddah and Tasmanian.

For Australians, the combination of 9 temporal and 8 non-temporal predictors gave a higher classification accuracy than the most effective analysis using 17 non-temporal predictors (Tables 7.3.3 & 4). Improvement is by 5.3-11.8% (11 groups) and by 1.3-5.2% (6 groups) compared to equivalent analyses based on non-temporal predictors only. For groups in general, there is 0.7-4.5% improvement (11 groups) and a 1.8% decrease to a 3.1% increase in accuracy (6 groups). This confirms the finding that temporal features are more effective in discriminating Australians than most groups, but not necessarily more than all groups.

Consideration of function 1 and 2 plots of discriminant score distributions and group means (Figs.7.3.2.1-4), shows that the Australians are well separated in the 6 groups analysis by a combination of the associated predictors (wide nasal aperture, low temporal squamous and acute petrous sagittal angle (Fn.2), and tympanic rim thickness (Figs.7.3.2.1 & 2). In the 11 groups analysis, Australians are at one extreme of the total distribution on the basis of function 2 predictors (wide nasal aperture, narrow parietals) (Figs.7.3.2.3). The centroids plot (Figs.7.3.2.4) shows the similarity of Australians to Veddah, New Britain and Tasmanians, and then to Gabon and Bushman. The intermediate position of Fuegian relative to Chinese and Eskimo groups is evident, as is the closeness of Bushman to Gabon and Poundbury to Chinese. Andamanese appear equally dissimilar to Chinese and Gabon, but otherwise the pattern of grouping is the same as that found when only temporal variables are used in the discriminant analysis.

Fig.7.3.2.1.Discriminant Fn. 1 & 2 Scores

6 Groups, 9 Temporal + 8 Non-Temporal Variables

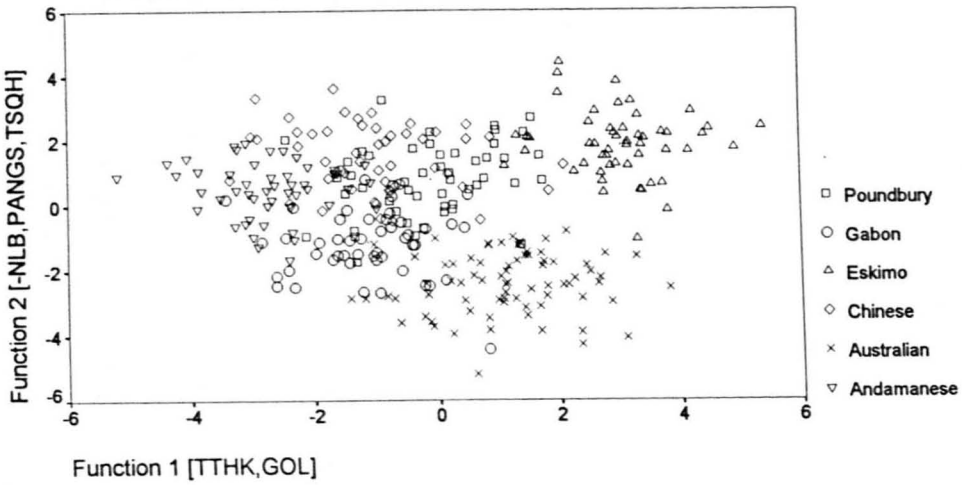


Fig.7.3.2.2. Group Means of Discriminant Scores

6 Groups, 9 Temporal + 8 Non-Temporal Variables

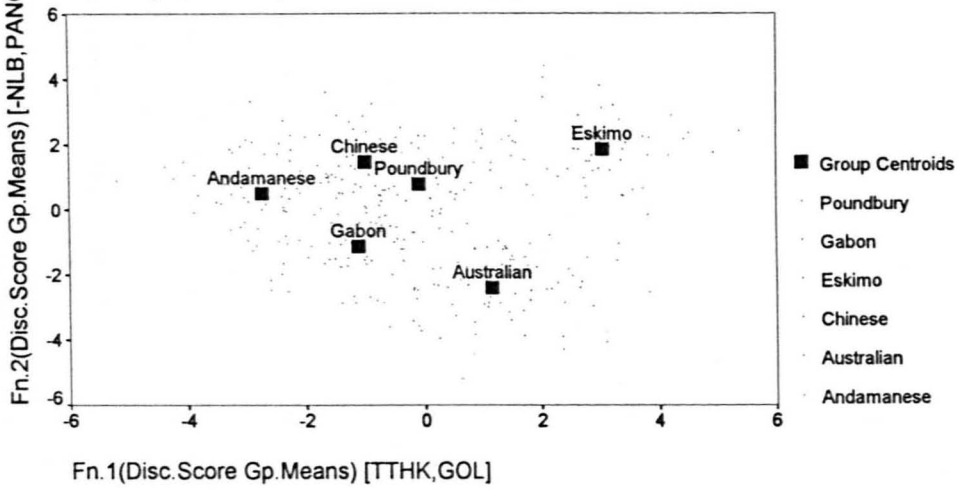


Fig.7.3.2.3.Discriminant Fn. 1 & 2 Scores

11 Groups, 9 Temporal + 8 Non-Temporal Variables

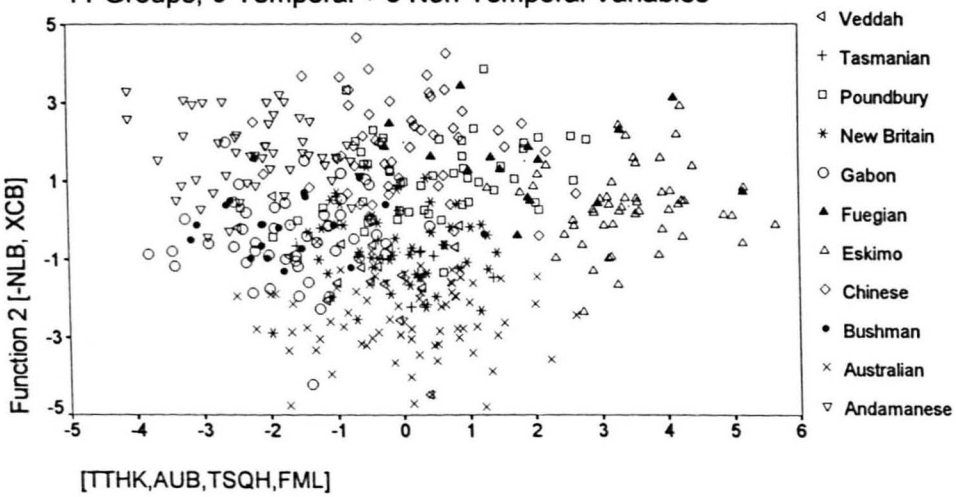
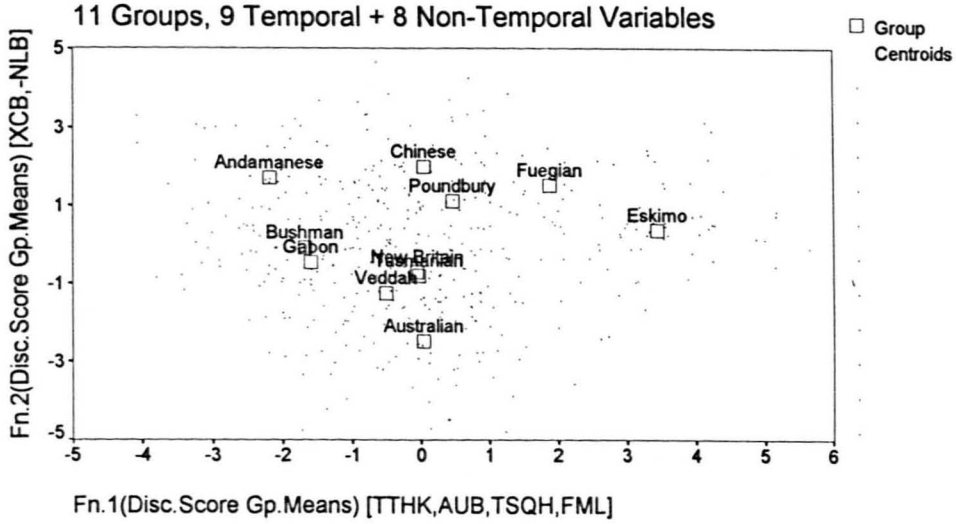


Fig.7.3.2.4. Group Means of Discriminant Scores

11 Groups, 9 Temporal + 8 Non-Temporal Variables



7.3.4 SUMMARY: COMPARISON OF DISCRIMINATION BY TEMPORAL AND NON-TEMPORAL VARIABLES

Comparison of classification accuracy resulting from discriminant analysis based on 17 non-temporal predictors with the classification accuracy resulting from discrimination analysis based on 17 temporal predictors leads to the following conclusions:

(i) The two combinations of 17 non-temporal variables used in this study yielded greater classification accuracy than 17 temporal variables. For Australians, the improvement in accuracy was up to 5.2% in the 6 groups analysis and up to 11.8% in the 11 groups analysis. For the groups overall, the accuracy improvement was up to 12.2% in the 6 groups analysis and up to 13.4% in the 11 groups analysis. However, it should be noted that discrimination effectiveness was found to vary considerably depending on which particular non-temporal variables are involved; not all non-temporal combinations are more effective than the temporal variable combinations in this study.

(ii) If the groups are not geographically distinct, there is greater improvement in discrimination based on non-temporal rather than on temporal variables.

(iii) The increase in classification accuracy by use of non-temporal rather than temporal variables is not as large for Australians as for groups in general. This indicates Australians are more effectively discriminated by temporal variables than most groups but not necessarily than all groups.

(iv) Discrimination by non-temporal variables results in many of the same patterns of similarities among groups as resulted from discrimination by temporal variables. For example:

The most similar groups are Chinese and Poundbury, Gabon and Bushman, and Australian and New Britain.

The Fuegian group is intermediate between Chinese and Eskimo in similarity.

At least one combination of non-temporal predictors

(mainly biauricular breadth and occipital arc) divides the total sample in two, with Chinese, Poundbury, Fuegian and Eskimo groups in one grouping and Gabon, Bushman, Veddah, Australian, New Britain, Tasmanian and Andamanese in the other. Eskimos are not outstanding as they were by discrimination based on temporal predictors.

(v) The non-temporal predictors which most effectively discriminate Australians are wide nasal aperture and small maximum parietal breadth.

(vi) As measured by classification accuracy, a combination of non-temporal and temporal variables was found to be even more effective as discriminant predictors than non-temporal variables only. The increased classification accuracy for Australians is 1.3%-5.2% (6 groups) and 5.3-11.8% (11 groups). For groups overall the improvement is less, up to 3.1% (6 groups) and up to 4.5% (11 groups). This suggests the addition of temporal predictors enhances the discrimination of Australians more than that of most groups.

7.3.5 DISCRIMINANT ANALYSIS SUMMARY

(a) Temporal variables can be used to distinguish modern groups from one another.

(b) Some combinations of non-temporal variables are more effective than temporal variables in discriminating modern groups.

(c) A combination of temporal and non-temporal variables was found to be more effective in discrimination and classification of modern groups than the same number of temporal variables alone, or non-temporal variables alone.

(d) Australians are among the groups most effectively discriminated from other modern groups whether by analysis with temporal or non-temporal variables.

(e) However, Australians are not exceptionally different in temporal features compared to all other modern groups. The only group that could be regarded as outstanding in temporal features is the Eskimo, and that is principally on the basis of one variable only, tympanic plate lateral rim thickness.

(f) The temporal predictors which contribute most to the discrimination of Australians from other modern groups are mastoid process length, depth and orientation. Two other variables which contribute substantially are glenoid fossa medial/lateral width (when 6 groups are involved), and petrous pyramid orientation (when 11 groups are involved). Thus the Australians are characterised by a long, transversely deep, acute angled mastoid process, a sagitally inclined petrous pyramid and a wide (medial/lateral) glenoid fossa.

(g) The non-temporal variables which contribute most to discrimination of Australians from other modern groups are maximum parietal breadth, nasal width, cranial length and frontal arc. Australians are particularly narrow across the parietals and have a very wide nasal aperture.

Distributions of discriminant function scores and group centroids based on temporal features indicate the following relationships exist among modern groups:

(h) Tasmanian and New Britain groups are most similar to, but not as extreme as Australians in temporal features. Their inclusion in the total sample reduces the contrast between Australians and other modern groups. Neither the New Britain nor Tasmanian group has as thick a tympanic plate rim as Australians. The Tasmanians also differ in having a considerably smaller, vertically inclined mastoid and coronally oriented petrous.

(i) The group least like Australians is the Chinese. The high temporal squamous, high tympanic plate, thin tympanic rim, vertically inclined mastoid and more coronally inclined petrous are Chinese temporal features which contrast most strongly with those of Australians.

(j) Chinese and Poundbury are the two groups least able to be distinguished on the basis of temporal features. They differ little in any temporal features other than the notably thinner tympanic plate rim and more vertically inclined mastoid of Chinese crania.

(k) Dissimilarity between Chinese and Eskimo features is bridged by similarity of Fuegians to both groups. Chinese and Eskimo differ most noticeably in tympanic height and rim thickness.

(l) Both Bushman and Veddah are very similar to Gabon. The most evident differences are the thinner tympanic plate and more acutely angled mastoid of the Bushman, and the more coronally oriented petrous of Veddah.

(m) The 2 strongest discriminant functions when 11 population groups are involved in the analysis, divides the sample in three. One grouping comprises Poundbury, Chinese, and Fuegian; another consists of only Eskimos; the third contains Australo-Melanesians, Africans, Andamanese and Veddah. It is the exceptionally thick tympanic plate rim of Eskimos which has isolated them. The other 2 groupings are separated on the basis of a combination of temporal squamous height, tympanic plate height and mastoid width. The "Chinese" grouping have a substantially higher temporal squamous and tympanic plate, and wider mastoid than the "African" grouping.

7.4.1 PURPOSE AND GENERAL PROCEDURE

To depict more clearly the affinities between groups suggested by discriminant analysis, cluster analysis was carried out and dendrograms constructed.

The type of cluster analysis applied was agglomerative hierarchical. The attributes used are the group means of the function scores from the 2 discriminant analyses based on 17 temporal variables, one analysis involving 6 population groups and the other, 11 groups.

Squared Euclidean distance (sum of the squared differences over all the variables) was the dissimilarity coefficient used to measure similarity of groups and hence to construct the resemblance matrix.

Of the clustering techniques available to convert the resemblance matrices to dendrograms, the following three were applied, first to the 6 main population samples and then to all 11 samples:

(i) Average Linkage Between Groups (UPGMA) method.

"The distance between two clusters is defined as the average of the distances between all pairs of cases in which one member of the pair is from each of the clusters." (Norusis 1993b:97).

This is the most widely employed method. It uses information about all pairs of distances, and the judgement of similarity between pairs of clusters is less extreme than through Complete Linkage.

(ii) Complete Linkage (furthest neighbour) method.

"The distance between two clusters is calculated as the distance between their two furthest points." (Norusis 1993b:97).

This method tends to produce extended dendrograms; it is least likely to cause chaining.

(iii) Ward's Minimum Variance clustering method.

"For each cluster the means of all variables are calculated. Then for each case, the squared Euclidean distance to the cluster means is calculated. These distances are summed for all of the cases. At each step, the two clusters that merge are those that result in the smallest increase in the

overall sum of the squared within-cluster distances." (Norusis 1993b:98).

The Ward method is the second most commonly used clustering technique. It is less extreme in assessment of similarity between pairs of clusters than by Complete Linkage and produces clusters which look well-defined. (Norusis 1993b:97,98; Everitt 1993:60-62,65,66; Romesburg 1984:15-23,123-135,137,139).

7.4.2 6 GROUPS PROCEDURE

As in discriminant analysis, the 6 groups concerned are the large, geographically distinct population samples, Andamanese, Australian, Chinese, Eskimo, Gabon and Poundbury. Altogether 9 analyses were carried out, and involved the three cluster methods applied in turn to the following 3 combinations of attributes:

1] All 5 (unweighted) discriminant score means.

2] All 5 (weighted) discriminant score means. To allow for the diminishing importance of discriminant functions from 1 to 5, the attributes were weighted by multiplying each discriminant function score mean by the percentage of between-groups variability accounted for by that function.

3] The first 3 (unweighted) discriminant score means only. The first 3 discriminant functions are the most reliable and account for 85.3% of the between-groups variability. Function 3 is the single function which is most effective in separating the Australian group.

7.4.3 6 GROUPS RESULTS

7.4.3.1 With all 5 unweighted discriminant score means as the attributes, the three cluster methods produce an identical cluster pattern (Figs.7.4.1.1-3).

Chinese and Poundbury are depicted as the closest groups. Australians, Gabon and Andamanese form a second cluster, with Andamanese the least similar of the three groups. Eskimo are represented as most different. The Chinese-Poundbury and Gabon-Australian-Andamanese clusters are more similar to each other than either is to the Eskimos.

DENDROGRAMS REPRESENTING CLUSTERING OF 6 GROUPS

ATTRIBUTES ARE GROUP MEANS OF FUNCTION SCORES FROM DISCRIMINANT ANALYSIS INVOLVING 17 TEMPORAL VARIABLES.

Fig.7.4.1.1-3.

ATTRIBUTES ARE ALL 5 DISCRIMINANT SCORE MEANS (UNWEIGHTED)

Fig.7.4.1.1. Dendrogram using Average Linkage (Between Groups)

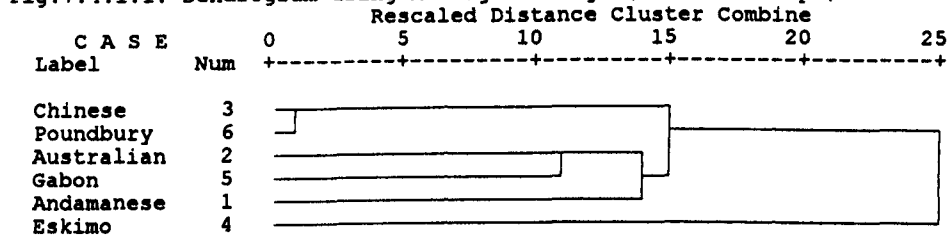


Fig.7.4.1.2. Dendrogram using Complete Linkage

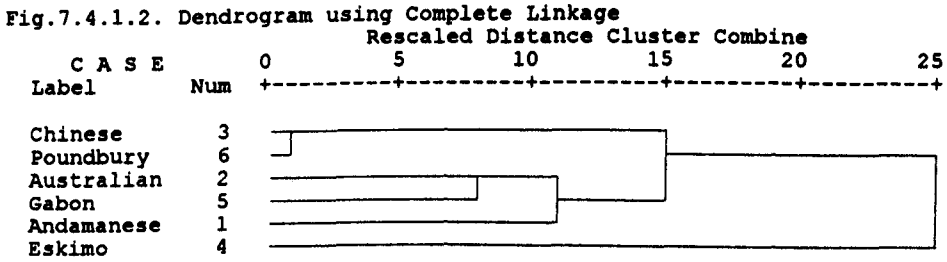
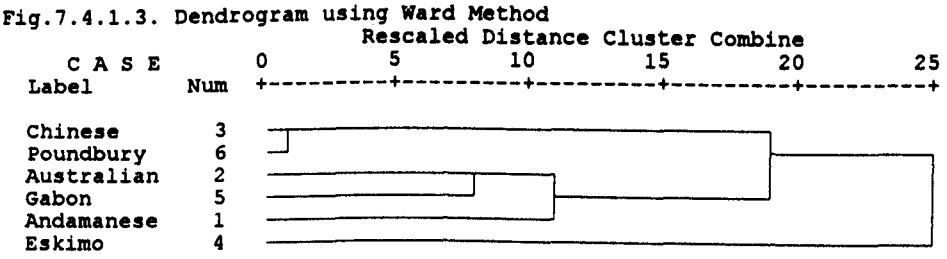


Fig.7.4.1.3. Dendrogram using Ward Method



Figs.7.4.2.1-3
ATTRIBUTES ARE ALL 5 DISCRIMINANT SCORE MEANS (WEIGHTED)

Fig.7.4.2.1 Dendrogram using Average Linkage (Between Groups)

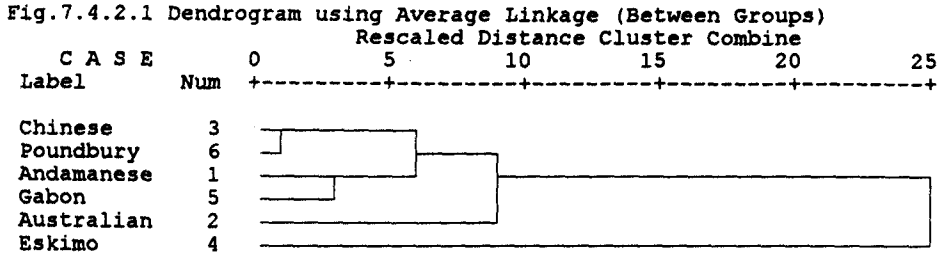


Fig.7.4.2.2. Dendrogram using Complete Linkage

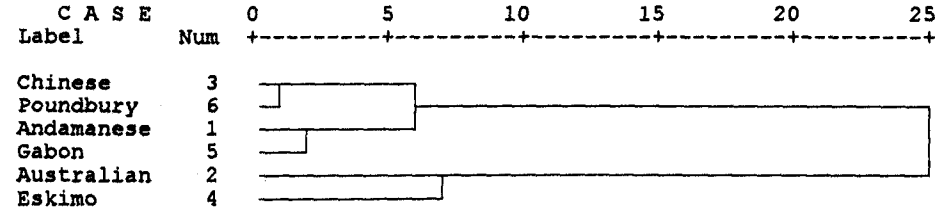
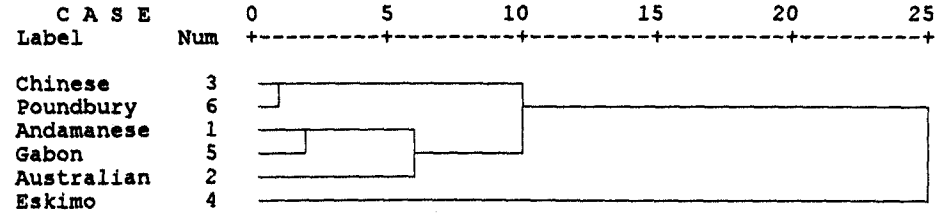


Fig.7.4.2.3. Dendrogram using Ward Method



Figs.7.4.3.1-3
ATTRIBUTES ARE FIRST 3 DISCRIMINANT SCORE MEANS (UNWEIGHTED)

Fig.7.4.3.1. Dendrogram using Average Linkage (Between Groups)

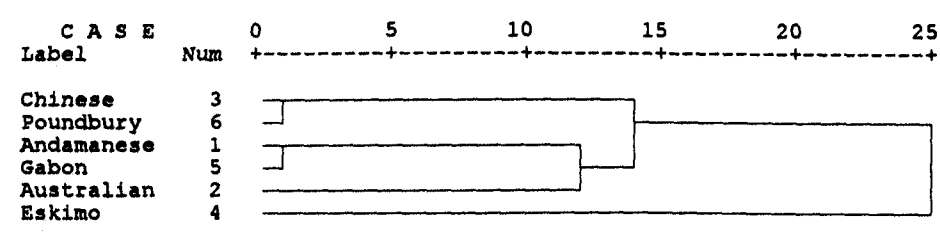


Fig.7.4.3.2. Dendrogram using Complete Linkage

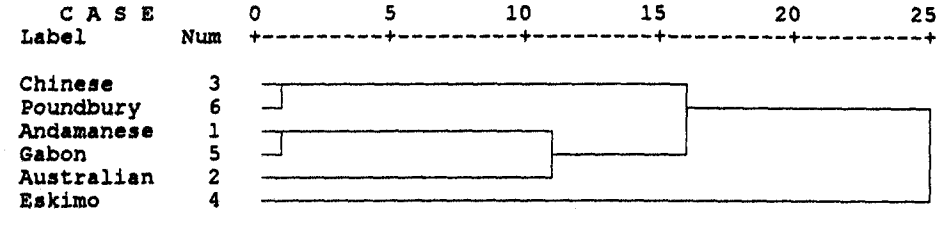
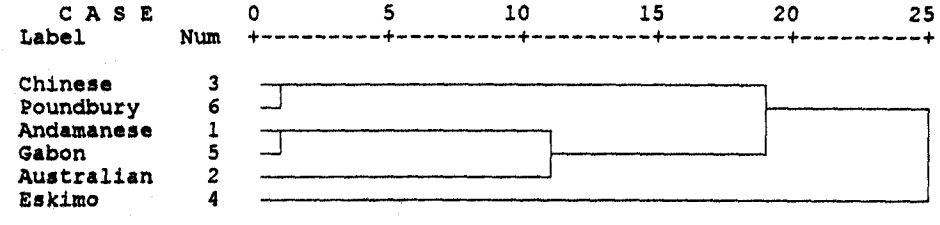


Fig.7.4.3.3. Dendrogram using Ward Method



7.4.3.2 When the 5 discriminant score means are weighted and used as the attributes, the pattern of clusters is the same for 5 of the groups as in the pattern resulting from 5 unweighted discriminant scores. But the Australians are placed differently by each of the three methods. The Ward's dendrogram is almost the same as the unweighted result, except that the Andamanese are more similar to Gabon than are the Australians (Fig.7.4.2.3).

According to Average Linking, the Australians are less similar to Eskimos than to the other 4 groups, but are also less like Chinese-Poundbury or Gabon-Andamanese than those 2 pairs are to each other (Fig.7.4.2.1).

Complete Linkage depicts the Australians as similar to the Eskimos as the Chinese-Poundbury cluster is to the Gabon-Andamanese cluster. (Fig.7.4.2.2).

7.4.3.3 If only the first 3 (unweighted) discriminant score means are the attributes, all three methods produce an identical pattern of clusters which is very similar to that produced for 5 unweighted discriminant score means, and for Ward's result with weighted attributes. As in the Ward dendrogram, Andamanese are depicted as more similar to Gabon than are Australians. The Andamanese group is shown as similar to Gabon as Chinese are to Poundbury (Figs.7.4.3.1-3).

7.4.4 11 GROUPS PROCEDURE

An equivalent series of 9 analyses was applied to 11 population groups, New Britain and the 4 small groups being added to the total sample. The 3 cluster methods (Section 7.4.1) were applied in turn to the following 3 attribute combinations:

1] All 10 (unweighted) discriminant score means.

2] All 10 (weighted) discriminant score means. Attributes were weighted by multiplying each discriminant function score mean by the percentage of between-groups variability accounted for by that function.

3] The first 4 (unweighted) discriminant score means only. The first 4 (most reliable) discriminant functions together account for 82.5% of between-groups variability. Function 4 is the single function which is most effective in separating the Australian group.

7.4.5 11 GROUPS RESULTS

7.4.5.1 When all 10 unweighted discriminant score means are the attributes, the 3 cluster methods yield different dendrograms (Figs.7.4.4.1-3). Common features in the 3 results are these:

*Eskimos are depicted as the most different group.

*Chinese and Poundbury are the groups most alike, Australian and New Britain the next most similar, and then Gabon and Veddah.

*Australian and New Britain groups are closer to Gabon, Veddah, Andamanese and Bushman groups than to the Chinese-Poundbury cluster.

*Gabon are more similar to Veddah than to Bushman or Andamanese.

*Tasmanians are not clustered with Australians or New Britain.

Differences between the 3 dendrograms are as follows:

The position of 3 of the 4 small groups vary from one dendogram to another. The Bushman group is found with the Gabon cluster in 2 of the 3 dendrograms (Figs.7.4.4.2 & 3), but by the Average Linkage Method, Bushman are shown as more dissimilar to the Gabon cluster than are Chinese and Poundbury (Fig.7.4.4.1). Tasmanians are depicted as the group second or third most dissimilar to others, and have varied closest links with Bushman, Fuegian, Andamanese or Eskimos (Fig.7.4.4.1-3). Fuegians are clustered with Chinese and Poundbury by 2 of the

DENDROGRAMS REPRESENTING CLUSTERING OF 11 GROUPS

ATTRIBUTES ARE GROUP MEANS OF FUNCTION SCORES FROM DISCRIMINANT ANALYSIS INVOLVING 17 TEMPORAL VARIABLES.

Figs.7.4.4.1-3

ATTRIBUTES ARE ALL 10 DISCRIMINANT SCORE MEANS (UNWEIGHTED)

Fig.7.4.4.1. Dendrogram using Average Linkage (Between Groups)

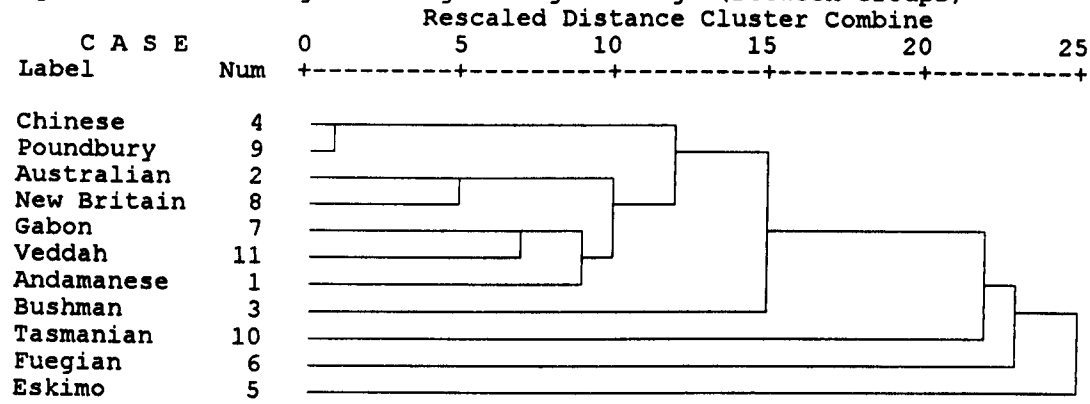


Fig.7.4.4.2. Dendrogram using Complete Linkage

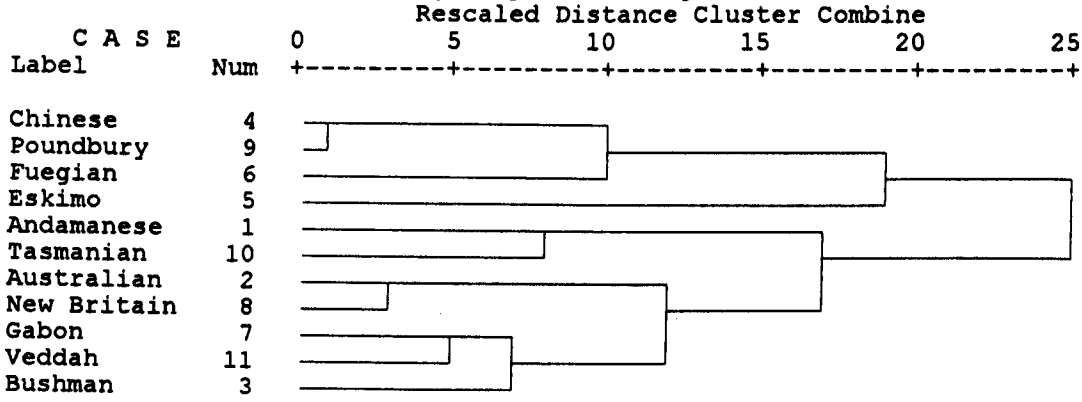
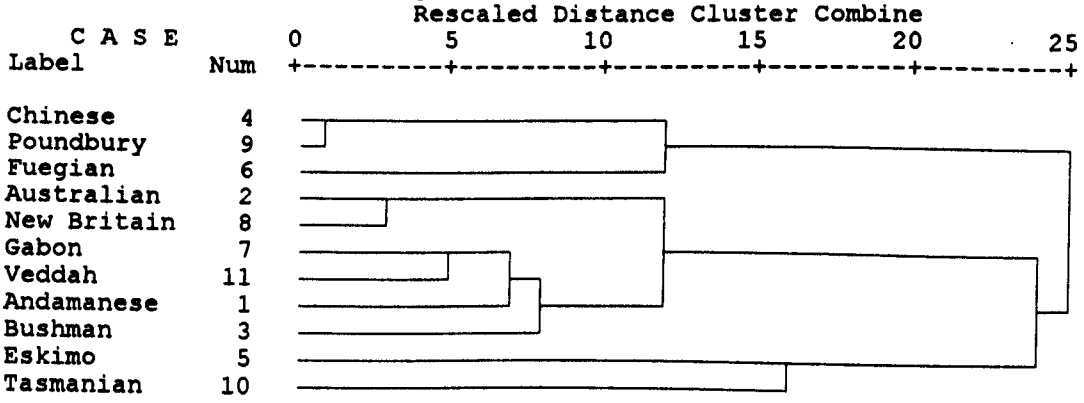


Fig.7.4.4.3 Dendrogram using Ward Method



Figs.7.4.5.1-3

ATTRIBUTES ARE ALL 10 DISCRIMINANT SCORE MEANS (WEIGHTED)

Fig.7.4.5.1. Dendrogram using Average Linkage (Between Groups)

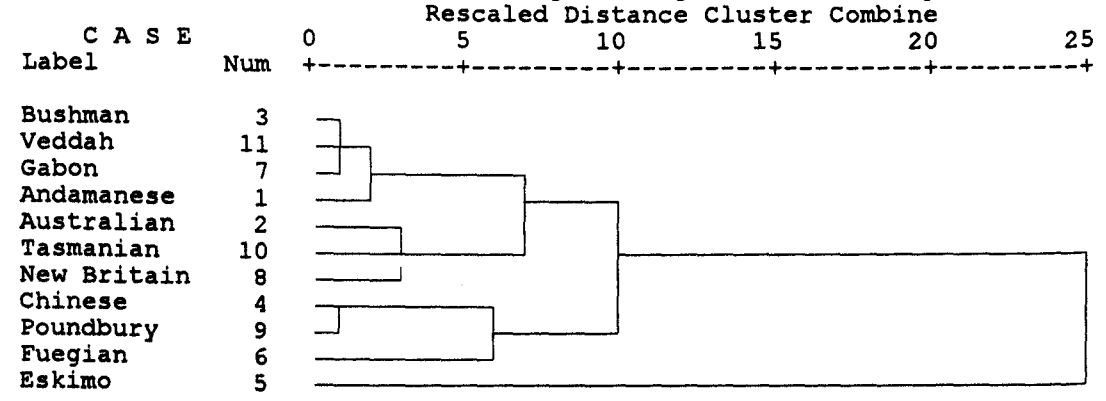


Fig.7.4.5.2. Dendrogram using Complete Linkage

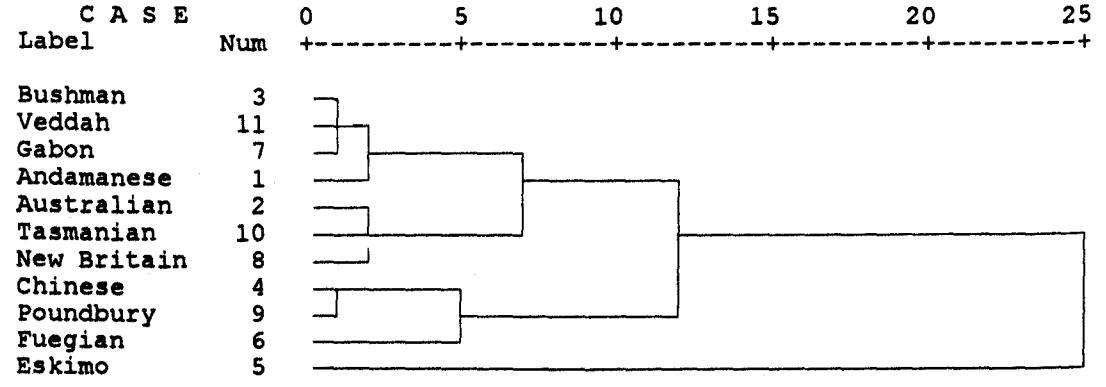
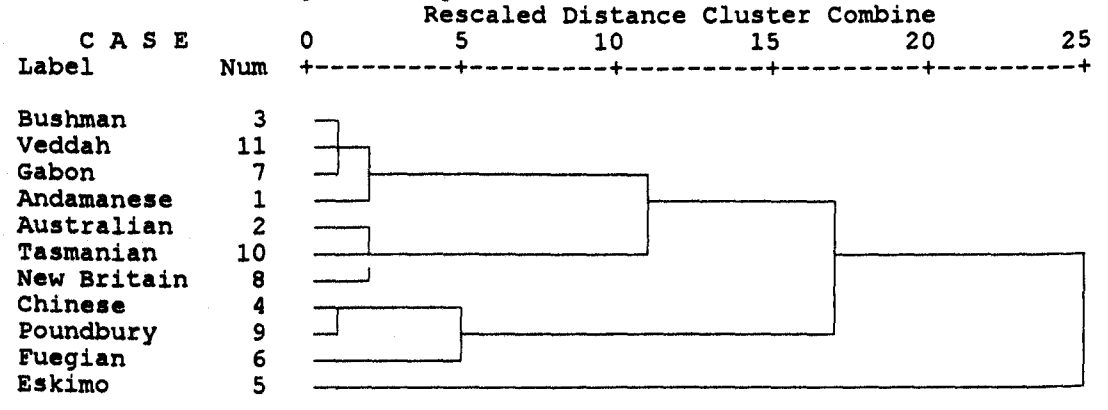


Fig.7.4.5.3. Dendrogram using Ward Method



3 methods (Figs.7.4.5.2 & 3), but by the Average Linkage Method they are depicted as one of the most distant groups, placed between Eskimos and Tasmanians (Fig.7.4.4.1).

7.4.5.2 When the attributes are 10 weighted discriminant score means, identical patterns are produced by the three cluster methods (Figs.7.4.5.1-3). Eskimos are depicted as most different. The other groups form 3 main clusters: Australian, New Britain and Tasmanian groups are equally similar in one cluster; Bushman, Veddah, Gabon and Andamanese form another cluster in which the Andamanese group is least similar; the third cluster consists of Chinese, Poundbury and Fuegian, the Fuegian group being the least similar. The African and Australian clusters are depicted as more similar to each other than to the Chinese cluster. The most similar groups are shown as Poundbury-Chinese, and Bushman-Gabon-Veddah.

7.4.5.3 If only the first 4 (unweighted) discriminant score means are the attributes, Average Linkage and Complete Linkage yield the same dendrogram (Fig.7.4.6.1 & 2). Eskimos are shown as most dissimilar to all other groups. The most similar groups are Bushman, Gabon and Veddah in one main cluster and Chinese and Poundbury in another. Fuegians are clustered with Chinese and Poundbury. The remaining 4 groups are in the Gabon cluster, with Australian and New Britain groups depicted as more similar than Andamanese and Tasmanian groups to Gabon-Bushman-Veddah groups. This is a similar pattern to that yielded when all 10 weighted discriminant score means were the attributes, except that Andamanese and Tasmanian groups are depicted here as less similar to Gabon and Australian groups respectively.

The Ward's dendrogram, (Fig.7.4.6.3), differs from the other two dendrograms, but only in the position of the Australian-New Britain pair. Instead of being in the Gabon main cluster and closest to Gabon-Veddah-Bushman groups, by Ward's method Australian and New Britain groups are clustered closest to Fuegians within the main Chinese-Poundbury cluster. Eskimos, though still depicted as the most different of all groups, are shown here as closer to the Chinese-Poundbury groups than to the Gabon cluster.

Figs.7.4.6.1-3

ATTRIBUTES ARE FIRST 4 DISCRIMINANT SCORE MEANS (UNWEIGHTED)

Fig.7.4.6.1. Dendrogram using Average Linkage (Between Groups)

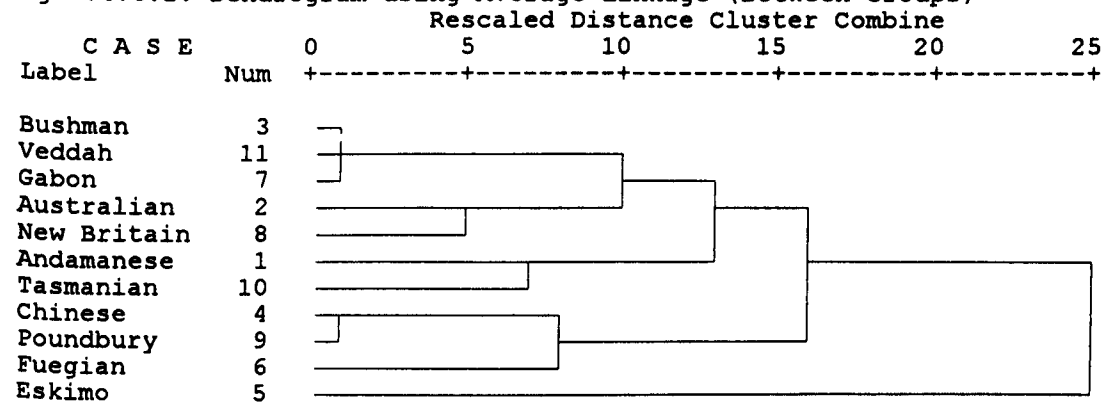


Fig.7.4.6.2. Dendrogram using Complete Linkage

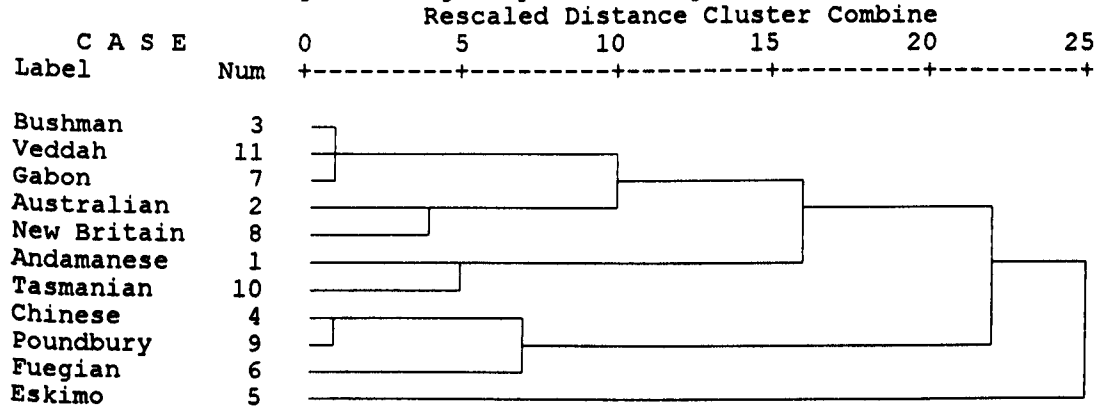
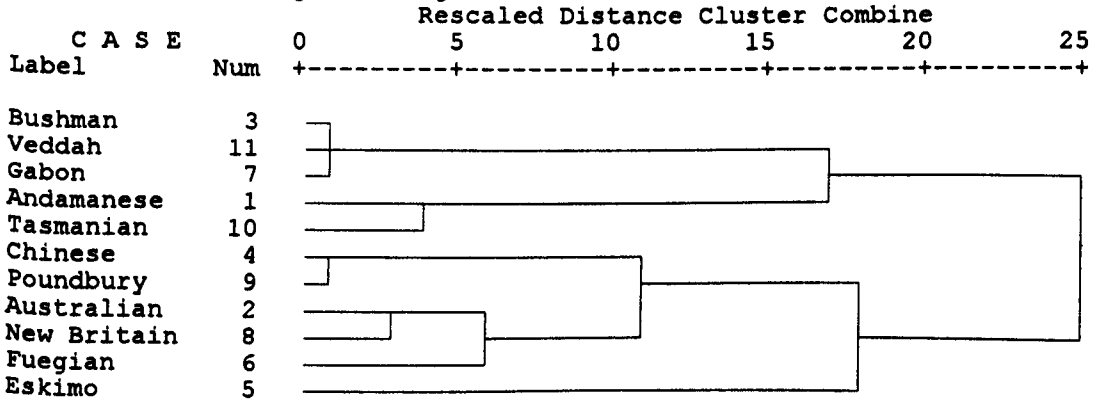


Fig.7.4.6.3. Dendrogram using Ward Method



7.4.6 CLUSTER ANALYSIS SUMMARY

In the light of factor and discriminant analysis results, the most common cluster patterns in the dendrograms for both 6 groups and 11 groups lead to the following conclusions:

(i) The 6 large sample, geographically distinct groups form 3 major clusters, Chinese-Poundbury, Australian-Gabon-Andamanese and Eskimo.

Discriminant analysis has shown that it is the extreme thickness of the Eskimo tympanic plate lateral rim, combined with the less important feature of a large glenoid fossa anterior/posterior length, which separates Eskimos as most different from all other groups.

Discriminant analysis results show that the other 2 major clusters differ from each other largely on the basis of temporal squamous height, mastoid width and tympanic plate height, Chinese-Poundbury groups having considerably higher temporal squamous, higher tympanic plate and wider mastoid process than Andamanese-Australian-Gabon groups.

The pattern of 3 major clusters is maintained when 11 groups are included in the cluster analysis. The Gabon and Chinese clusters are depicted as more similar to each other than they are to Eskimos in 8 of the 9 dendrograms involving 6 groups and in 6 of the 9 dendrograms involving 11 groups.

(ii) Australians are depicted as more similar to Gabon than to the Chinese-Poundbury cluster in 15 of the 18 analyses, equally similar to both in 2 analyses and more similar to Chinese-Poundbury in only one analysis. Like others in the Gabon cluster, Australians differ from Chinese and Poundbury in having a low temporal Squamous, low tympanic plate, and a narrow mastoid. They also contrast strongly with Chinese in having an acutely inclined mastoid, a sagitally inclined petrous, a smaller petrous/tympanic angle and a more robust tympanic plate.

(iii) In all 18 analyses, the Andamanese group is clustered with Gabon rather than with Chinese-Poundbury.

Andamanese are depicted as more similar than Australians to Gabon in 12 of the 18 analyses, the Australian mastoid process being considerably deeper, longer and more acutely inclined.

(iv) Poundbury and Chinese are the groups which consistently show greatest similarity even when the 5 less geographically distinct groups are added to the analysis. Discriminant analysis has shown that Chinese and Poundbury groups are very alike in all important predictors except 2; the Chinese have a thinner tympanic rim and more vertically inclined mastoid than Poundbury.

The 9 dendrograms involving 11 groups contributed the following additional information:

(v) The group depicted in all 9 dendrograms as most similar to Australians is New Britain, though the pair are not as similar as Chinese and Poundbury. They are particularly alike in the features they have in common with other members of the Gabon major cluster, as outlined in "(i)". In addition, results from factor analysis, discriminant analysis and the absolute mean values reveal they are very similar in having a long, deep mastoid process and large glenoid fossa dimensions. Australians differ from New Britain in having a substantially thicker tympanic rim, a more acutely inclined mastoid process and smaller petrous sagittal and petrous-tympanic angles.

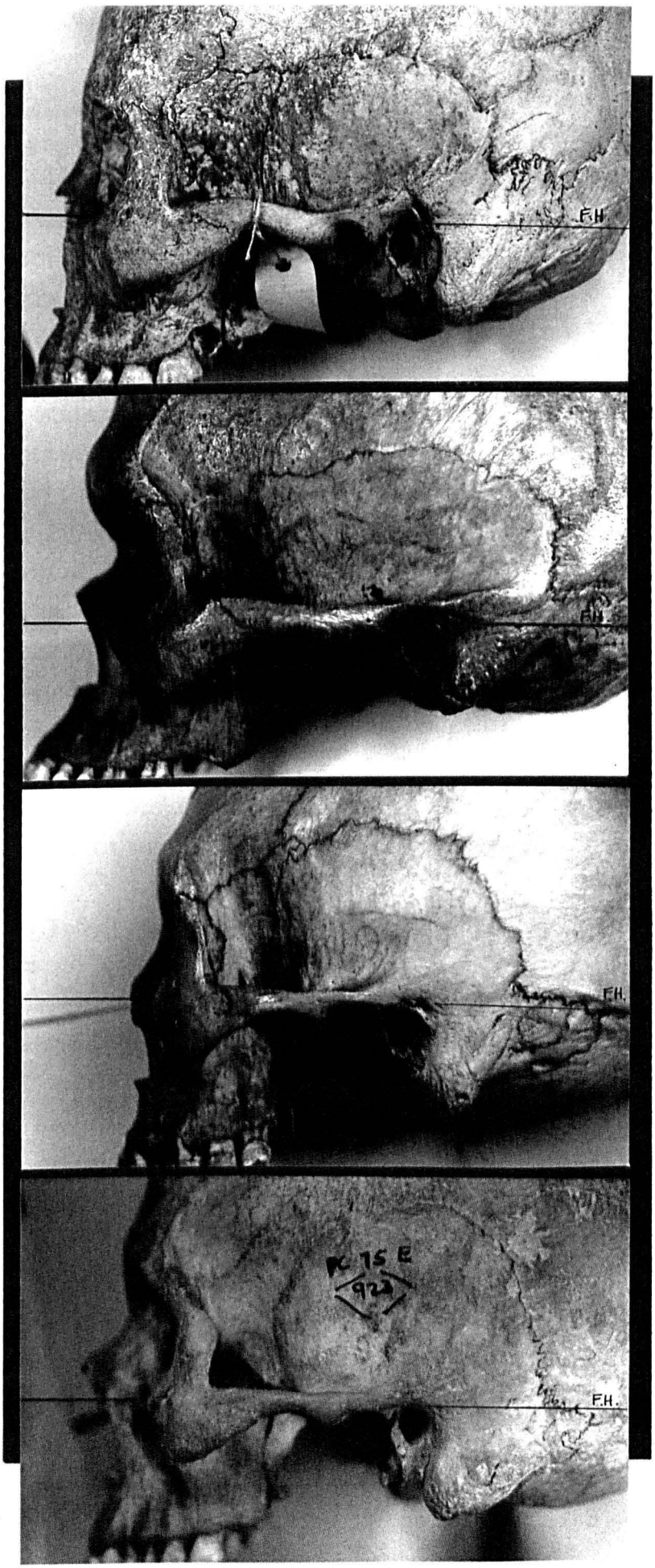
(vi) The position of Tasmanians in dendrograms varies. For example, they are depicted as equally similar to Australian and New Britain groups in 3 of the 9 analyses, and most similar to Andamanese in 4 of the 9 analyses. As for New Britain, Tasmanians are particularly like Australians in the features of shared similarity with Gabon, Bushman and Andamanese (low temporal squamous, low tympanic plate, narrow mastoid). Tasmanians are also like Australians and New Britain in differing from Gabon, Bushman and Andamanese by having large glenoid fossa dimensions. But Tasmanians differ noticeably from Australians by having a coronally inclined petrous pyramid, and a mastoid which is much shorter, less deep and inclined vertically. It is these mastoid features which Tasmanians have in common with Andamanese.

(vii) Veddah is depicted as the group closest to Gabon in the 9 dendrograms for 11 groups. The Bushman group is equally close in 6 of the 9 analyses. Discriminant analysis has shown these three groups are particularly alike in features separating them from the Chinese-Poundbury cluster on the basis of their low tympanic plate, low temporal squamous and narrow mastoid process. Bushman differ from Gabon and Veddah in having a comparatively thinner tympanic rim and a more acute mastoid angle. Veddah differ from the two African groups in having a more coronally oriented petrous and larger petrous-tympanic angle.

(viii) Fuegians are clustered with Chinese and Poundbury in 8 of the 9 analyses, and are closest to Eskimos in the remaining analysis. In discriminant analysis, the Fuegian group has been depicted as equally similar to Eskimos and Chinese. For example, Chinese differed considerably from Eskimos on the basis of tympanic rim thickness; Fuegian bridge that gap with a tympanic rim of intermediate thickness.

Pictured in Plate 7.1 are some of the modern human temporal features visible in lateral view which are useful in distinguishing major modern human groups, Africans (represented by Gabon), Australians, Chinese and Europeans (represented by Poundbury).

Plate 7.1
MODERN HUMAN
TEMPORAL REGION
Some Characteristics
seen in
Lateral View



AFRICAN

(Gabon, '64:6/7/17)
Small, vertically tending mastoid process.

AUSTRALIAN

(Aus 60/3)
Long, narrow, acutely inclined mastoid process; low temporal squamous; thick tympanic rim; horizontally inclined suprameatal crest.

EAST ASIAN

(Chinese 7.6383)
Vertically tending, wide, large volume mastoid process; high temporal squamous; large suprameatal crest angle.

EUROPEAN

(Poundbury, PC 923)
Wide, large volume mastoid process; high temporal squamous; horizontally inclined suprameatal crest.

7.5 DISCRIMINATION OF 6 RECENT MODERN HUMAN GROUPS AND 3 TERMINAL PLEISTOCENE MODERN HUMAN FOSSILS

7.5.1 PURPOSE AND PROCEDURE

If modern human populations can be discriminated by temporal features, how recent are the between-groups temporal morphological differences? For example, can discriminant analysis based on temporal variables successfully classify terminal Pleistocene crania according to their region of origin? To test this, the discriminant analysis involving 17 temporal variables and 6 core groups was repeated but with 3 terminal Pleistocene modern human fossils included as ungrouped cases. The 3 fossils are

(i) Zhoukoudian Upper Cave 101 (UC102) and Upper Cave 102 (UC102) dated to 29-24ka ago (Hedges 1992a:155).

(ii) Kanalda from Australia, undated but morphologically similar to material from Coobool Creek, dated 14.3ka ago (Brown 1993:220).

Since the fossil cases were not included in the calculation of the discriminant function, the statistical results relating to recent modern crania are as in Tables 7.2.1.1-4 for the 6 Groups Analysis, with slight adjustment in quantitative data to allow for the classification of 3 additional cases.

7.5.2 RESULTS: (Tables 7.5.1 & 2 and Figs.7.5.1-3)

Based on temporal bone features, discriminant scores for all 3 fossils are well within the recent modern human range. UC102 is classified with recent modern Chinese, and Kanalda and UC101 with recent modern Australians (Table 7.5.1). Discriminant Scores for each of the 3 fossils and discriminant mean scores for the 6 core groups are recorded in Table 7.5.2. Distribution of discriminant scores from function 1 and 2 (Fig.7.5.1) shows that the UC102 discrimiant scores are within recent modern Chinese distribution and that the Kanalda discriminant scores are within the recent modern Australian distribution, Kanalda's score lying close to the Gabon centroid and UC101 lying close to the Australian centroid.

The pattern of Discriminant Score Means of Functions 3 and 2 (Fig.7.5.2) shows Kanalda and UC101 closest to the Australian centroid and UC102 closest to the Chinese centroid.

TABLE 7.5.1
6 RECENT MODERN HUMAN GROUPS & 3 TERMINAL PLEISTOCENE MODERN HUMAN FOSSILS:

17 TEMPORAL PREDICTORS, OBSERVED CLASSIFICATION RESULTS.

No. of Group	Cases	Predicted Group Membership					
		AND	AUS	CHI	ESK	GAB	POU
AND	50	47	0	1	0	2	0
		94.0%	.0%	2.0%	.0%	4.0%	.0%
AUS	76	4	65	0	3	1	3
		5.3%	**85.5%**	.0%	3.9%	1.3%	3.9%
CHI	50	0	1	35	0	1	13
		.0%	2.0%	**70.0%**	.0%	2.0%	26.0%
ESK	52	0	4	0	45	1	2
		.0%	7.7%	.0%	**86.5%**	1.9%	3.8%
GAB	50	2	5	3	0	40	0
		4.0%	10.0%	6.0%	.0%	**80.0%**	.0%
POU	50	2	1	14	2	3	28
		4.0%	2.0%	28.0%	4.0%	6.0%	**56.0%**
KANALDA	1		KANALDA				
UC101	1		UC101				
UC102	1			UC102			

Total No. 328 — Total Correctly Classified: **79.3%**

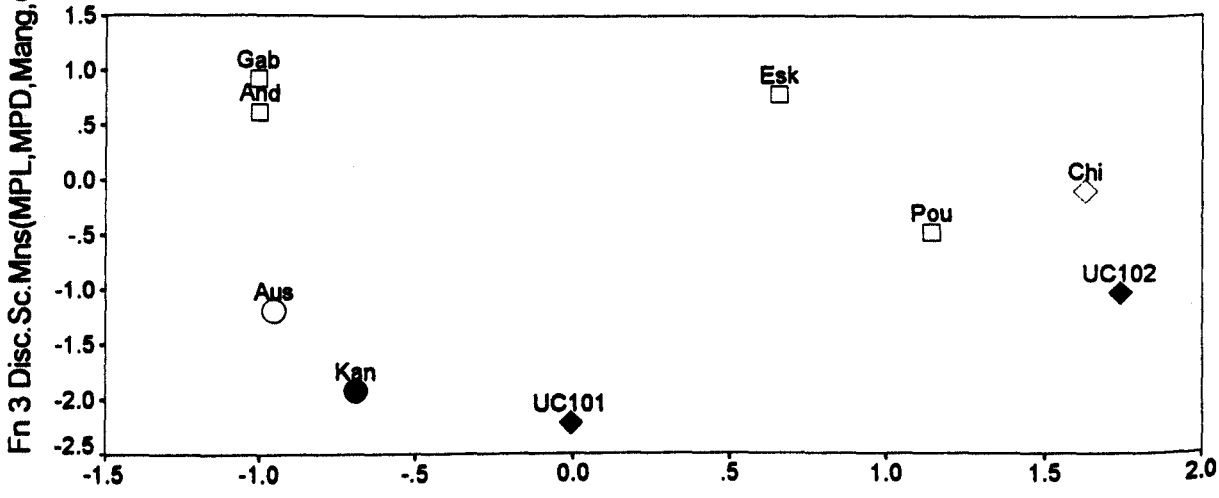
TABLE 7.5.2
6 RECENT MODERN HUMAN GROUPS & 3 TERMINAL PLEISTOCENE MODERN HUMAN FOSSILS:

17 TEMPORAL PREDICTORS, GROUP MEANS OF THE FIRST 5 of 10 DISCRIMINANT FUNCTION SCORES.

GROUP	FUNC 1	FUNC 2	FUNC 3	FUNC 4	FUNC 5
AND	-1.420	-1.001	.624	1.260	.037
AUS	.670	-.953	-1.181	-.031	-.103
CHI	*-1.206*	*1.627*	-.094	-.127	-.436
ESK	2.567	.659	.787	.368	-.010
GAB	-.451	-1.006	.923	-1.325	.020
POU	-.612	1.144	-.477	-.142	.545
Kanalda	-.546	-.688	-1.911	.336	-.401
UC101	.745	-.008	-2.217	-.050	-.108
UC102	*-1.797*	*1.737*	-1.024	-3.141	.042

Fig.7.5.2. Discriminant Function Scores

Modern Humans: 6 recent groups & 3 terminal Pleistocene fossils.

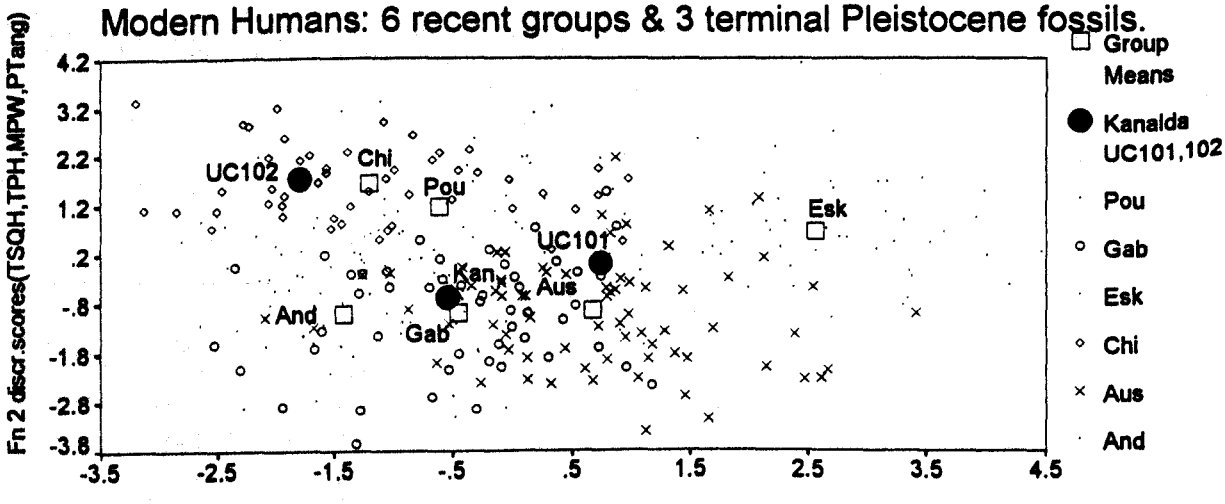


Fn 2 Disc.Score Means (TSQH,TPH,MPW,PTang)

Kanalda & UC101 are classified with Australians, UC102 with Chinese.

Fig.7.5.1.Discriminant Function Scores

Modern Humans: 6 recent groups & 3 terminal Pleistocene fossils.



Fn 1 discr.scores(TTHK,Gap)

The 3 Hs.fossil discriminant scores are in recent modern distributions,

Kanalda & UC101 with Australians, UC102 with the Chinese.

7.5.3 DISCUSSION

The classification of UC102 with recent modern Chinese crania and Kanalda with recent modern Australian crania is consistent with regional distinctions in the temporal bone in East Asia and Australia being at least as old as the local fossils. But classification of UC101 with Australians suggests the existence of a wider temporal bone variation in East Asian crania 25 ka ago than today. (This may or may not apply to Australian crania of the time; Kanalda is 10 ka more recent).

A variety of affinities for the Upper Cave modern human fossils have been suggested by different researchers. Weidenreich (1943:251) was surprised that the 3 Upper Cave crania do not have a typically Mongoloid appearance and also are so unlike each other in general cranial features. He attributed Melanesian affinity to UC102 and considered UC103 most resembles Eskimos (The temporal region of UC103 is not adequately preserved for inclusion in this study). He found that UC101 has European Cromagnon, African and Australian cranial similarities, yet described it as "proto-Mongoloid". Howells (1960:300,301) said the Upper Cave skulls resemble Amerindians which he described as unspecialised Mongoloid. Turner (1992b:426) recognised in the Upper Cave crania the same Sinodont (Mongoloid or North Asian) dental morphology typical of present day Chinese, Amerindians and Eskimos. Kamminga and Wright dispute this association, and on the basis of general cranial variables they found UC101 and UC103 most similar to Australo-melanesians and within the African cluster (Kamminga & Wright 1988:745,753,762; Kamminga 1992:384,387; Wright 1992:128,133). Habgood (1985:373) also regarded UC101 as very like Australian crania in general appearance.

The affinities of Upper Cave UC101 and UC102 as indicated in this study by temporal features do not resolve the controversy, but do support a number of apparently conflicting suggestions made on dental and general cranial evidence:

(i) UC101 has Australian/African affinity (Habgood, Kamminga and Wright);

(ii) Upper Cave morphology and affinities are diverse when more than one crania are considered (Weidenreich);

(iii) The temporal morphology diversity seen in crania of identical provenance (UC101, UC102) is consistent with an unspecialised Mongolian pattern (Howells, Weidenreich).

7.5.4 SUMMARY:

DISCRIMINANT ANALYSIS of RECENT & FOSSIL MODERN HUMANS

The temporal bone morphology of the Upper Cave and Kanalda fossils is well within the recent modern human range. Temporal variables are effective in classifying the 3 terminal Pleistocene modern human fossils within recent modern human populations and in 2 cases from the fossil's respective region of origin. The classification of Kanalda with recent Australians is consistent with distinctive Australian temporal morphology being constant for at least 14 ka. The Chinese Zhoukoudian UC102 is classified with recent Chinese, but UC101 is classified with recent Australians. This may mean there was wider variation in the temporal bone of Chinese modern humans 25ka ago, including characteristics typical of recent modern Australians. But the question cannot be settled on the basis of just 1 Australian and 2 Chinese fossils.

Dental and general cranial morphology of the Upper Cave crania have prompted a variety of proposals as to their affinity. The temporal morphology supports some of these claims but does not resolve the controversy:

* The closer temporal similarity of UC101 to recent Australians and Africans rather than to recent Chinese coincides exactly with the findings of Habgood, Kamminga and Wright from studies based on general cranial features (Habgood 1985:373; Kamminga & Wright 1988:745,753,762; Kamminga 1992:384,387; Wright 1992:128,133).

* The diversity seen in the temporal morphology of UC101 (typical of recent Australians) and UC102 (typical of recent Chinese) is consistent with a possible unspecialised, early or proto-Mongolian pattern referred to by Howells (1990:300,301) and Weidenreich (1943:251).

* The population affinity suggested by temporal morphology is consistent for UC102 but not for UC101 with dental evidence of a Sinodont pattern in Upper Cave crania (Turner1992b:426)

Since these conclusions are drawn from an analysis involving such a small fossil sample, they must be treated with caution. Nevertheless, the results attest to the interestingly elusive affinity of the Upper Cave crania.

Chapter 8

TEMPORAL BONE VARIATION: *H.ERECTUS TO MODERN HUMANS*

8.1 THE TEMPORAL BONE ANATOMY OF HOMO ERECTUS: A collation of accounts in the literature.

8.1.1 DESCRIPTIVE FEATURES OF THE HOMO ERECTUS TEMPORAL BONE

8.1.1.1 SQUAMOUS PLATE

(1) Squamous Height. The squamous plate of *H.erectus* is described as considerably lower than that of modern human; within *H.erectus*, the squamous is not as low in Ngandong as in the other Asian representatives (Macintosh & Larnach 1972:3,5; Rightmire 1990:176; Santa Luca 1980:107-109; Weidenreich 1943:43,44,200).

(2) Squamous Shape. The *H.erectus* squamous plate has been described as triangular, (Weidenreich), or trapezoidal (Santa Luca). Weidenreich described the superior border, the squamosal suture, as straight or only slightly curved. Although Santa Luca does not regard the Ngandong squamous either as low or as flat as that of other Asian *H.erectus*, he considers the Ngandong squamosal suture as only slightly curved compared to the high curve commonly associated with the squamous of modern man (Andrews 1984:174; Macintosh & Larnach 1972:3,5; Rightmire 1990:176; Santa Luca 1980:105,107-109; Weidenreich 1943:43,200; 1951:269). Santa Luca pointed out that the squamosal sutures in Ngandong crania appear somewhat straighter now than they originally were because part of the fragile superior edge of the squamous is missing, the original curve being indicated by vertical striations on the parietal immediately superior to the remaining plate. The same may have been true of other *H.erectus* crania; certainly, such a view is consistent with Weidenreich's drawings of *Sinanthropus* crania and with personal observation of similar damage to squamous plates in collections of modern human crania. If so, and if Ngandong is accepted as *H.erectus*, a low and flat temporal squamous would not be as extreme a characteristic of *H.erectus* compared to modern humans as previously thought.

(3) Supramastoid crest. The supramastoid crest, the ridge of bone posterior to, in line with and usually continuous with

the zygomatic root, is typically very prominent in *H.erectus*, a characteristic anthropoid feature. The same degree of development of the crest is not achieved in modern humans as in *H.erectus*, though variation in the degree of prominence occurs in both groups (Santa Luca 1980:107,108; Weidenreich 1943:201). As Rightmire points out, maximum cranial breadth is at the supramastoid crest level for all *H.erectus* (Rightmire 1990:176). Andrews regarded it as a primitive retention (Andrews 1984:174).

(4) Suprameatal Crest Angle. At, or just behind auriculare, the section of transition of zygomatic root to supramastoid crest angles upwards more vertically relative to the Frankfurt plane than in modern humans. This is especially true of Asian (Javan) *H.erectus* (Rightmire 1990:176,178; Santa Luca 1980:107; Weidenreich 1943:43). While pointing out that this angle in *H.erectus* (~30°) is intermediate between that found in gorilla (>40°) and modern humans (~0°), Weidenreich also considers that the inclination is dependent on the relative sizes of face and calvaria; the larger the face relative to calvarial size, the more vertical the inclination (of suprameatal crest) (Weidenreich 1943:43).

8.1.1.2 GLENOID FOSSA

(5) Glenoid Fossa Size and Shape. The glenoid (mandibular) fossa of *H.erectus* is described as particularly deep and narrow in the antero-posterior direction (Weidenreich 1951:273 1943:27,46,47,50). Weidenreich thought the deepening of the glenoid fossa from apes to *H.erectus* was not related to mastication, since no correlation had been found between condyle size and fossa size, the articular disc compensating for fossa size. Rather he associated the deepening and sagittal compression of the fossa with the more vertical inclination of the tympanic plate attributing both to brain expansion (Weidenreich 1943:49,50).

(6) Entoglenoid Process. It is difficult to reach a clear and unambiguous consensus from the proposed definitions of this feature which are less than consistent and sometimes vague. The name itself is misleading since a "process" suggests some sort of a projection or extension from a surface, in this case from the medial wall of the glenoid cavity. Certainly that is implied in this definition.

"The entoglenoid process is the inferior projection of the articular surface at the medial edge of the articular eminence." (White et al.1991:68).

However, most definitions assume that the entoglenoid process comprises the entire medial wall of the glenoid process. There appear to be 4 main variations in composition of that wall:

a) the squama of the glenoid fossa alone;
b) glenoid fossa squama and some sphenoid contribution, but no sphenoid spine.
c) glenoid fossa squama and some sphenoid contribution including an inferiorly projecting sphenoid spine, usually pointed, which forms the lower part of the medial wall;
d) glenoid fossa squama and a large crest-like process of sphenoid, or sphenoid and squama in equal parts.

[a) and b) would more accurately be described as a slope rather than a process. Rightmire refers to it as a pyramid.

Anthropoids exhibit condition d) only. In Sinanthropus, only condition b) occurs, but in other Asian and African *H.erectus* both conditions a) and b) are found. Modern humans exhibit conditions a),b) and c). A sphenoid spine may occur in a particular *H.erectus* cranium, but not as part of the glenoid fossa medial wall. Nor does a sphenoid spine necessarily form part of the glenoid fossa medial wall in modern humans.(Aiello & Dean 1990:88; Rightmire 1990:24,48,94,98,151,167,177,189, 236; Weidenreich 1943:46,47,202; 1951:273).

(7) Entoglenoid/Tympanic Recess. The glenoid fossa narrows medially to form a deep cleft or recess between the entoglenoid process (as defined above) and the tympanic plate. Weidenreich linked the formation of this recess to the anteroposterior compression of the fossa and the orientation of the tympanic plate and claimed it is absent in anthropoids and modern humans (Rightmire 1984:90; 1990:20,67,94,98,151, 167,177,189; Weidenreich 1943:47).

(8) Postglenoid Process. In *H.erectus* the postglenoid process is greatly reduced in size, being described in Ngandong as vestigial and in the other *H.erectus* groups as a low broad-based ridge. In apes the large postglenoid process functions as the posterior wall of the glenoid fossa, hindering the posterior movement of the condyle, but in *H.erectus* the more vertical tympanic plate acts as the posterior wall, rendering the postglenoid process

comparatively superfluous. However, in modern humans there is extreme variation from ape-sized postglenoid process to negligible (Weidenreich 1943:51; 1951:273,274).

8.1.1.3 MASTOID PROCESS

(9) Mastoid Size. A few writers have associated a small mastoid process with *H.erectus* (Delson et al.1977:274; Le Gros Clark 1972:99; Macintosh & Larnach 1972:2,5,6). Many *H.erectus* crania have damaged or missing mastoid processes, but it is sometimes possible to estimate the approximate size on crania where the exposed transverse cross-section of the mastoid process exists. Although less certainty is associated with length than with depth or width predicted in this way, nevertheless it is clear that mastoid process size varies considerably in *H.erectus*, as it does within and between modern human populations. Within the one modern population, males tend to have larger processes than females; Weidenreich associated the smaller processes within the one *H.erectus* group with female or adolescent individuals. In general, Ngandong crania appear to have larger mastoid processes than other Asian *H.erectus*, but within the modern human range. Mastoid projection in gorilla is small, in Pan is negligible (Rightmire 1990:176; Weidenreich 1943:62,63,205; 1951:280).

(10) Mastoid Shape. The mastoid transverse cross-section in Sinanthropus is triangular. Santa Luca described the Ngandong mastoid process as either pillar-like and narrow or mound-like and broad-based. In modern man the most consistent mastoid process shape is conical with an elliptical or semi-elliptical transverse cross-section (Santa Luca 1980:108; Weidenreich 1943:205; 1951:279).

(11) Mastoid Orientation. Viewed from norma occipitalis, the *H.erectus* mastoid process does not descend vertically as in (adult) modern humans, but bends medially as if tucked under the cranium. (Rightmire 1990:236; Weidenreich 1943: 22,62,205; 1951:279).

(12) Mastoid Crest. This feature is variably developed in *H.erectus*, but usually it is strongly pronounced, more so than in modern humans. No equivalent crest occurs in apes (Rightmire 1990:176; Weidenreich 1943:63,205).

(13) Digastric Groove. Macintosh and Larnach claim the digastric groove is wide in *H.erectus*, but other authors

describe it as variably expressed in *H.erectus*, and extremely so in modern humans. (From personal observation the digastric groove in modern human crania is extremely variably expressed in width, depth and shape). In Sinanthropus the groove is situated more posteriorly relative to the mastoid process than is the case in modern humans; in Ngandong it is usually a short deep and narrow cleft. In apes the groove is broad and smooth. (Andrews 1984:175; Macintosh and Larnach 1972:2; Santa Luca 1980:108; Weidenreich 1943:63,205; 1951:280).

(14) Mastoid Fissure. Santa Luca points out that in all Ngandong and Sinanthropus crania," a large fissure separates the mastoid process from the petrosal crest of the tympanic plate", and that no such fissure exists in modern humans since the crest fuses with "the anteromedial edge of the mastoid process" (Santa Luca 1980:108).

8.1.1.4 TYMPANIC PLATE

(15) Tympanic Orientation: Vertical/Horizontal. The tympanic plate orientation in Asian *H.erectus* is less vertical than in modern man, similar to that of gorilla, and less horizontal than in *Pan* (Weidenreich 1943:53,202; 1951:275).

(16) Tympanic Orientation: Relative to the Sagittal Line Weidenreich noted the Asian *H.erectus* tympanic plate "axis" is almost perpendicular to the sagittal line, that anthropoids have a similar condition and that in modern humans the angle is usually more acute. For example, he found the angle for Sinanthropus is 87°-90°, while for most modern humans the angle is 56°-80° though for 17% it is 80°-92°. (Weidenreich 1943:53, 202). Dean and Wood (1982:161,162,168) found the tympanic angle in African crania attributed to *H.erectus* is less coronally inclined than in apes and at the more coronally inclined end of the modern human range. They associated reduction in coronal inclination of the tympanic with decrease in its length. [Note: Weidenreich measured tympanic angle as the orientation of the Glaserian fissure. In this study, that is approximately equivalent to the angle of the tympanic plate anterior side, the tympanic axis orientation being defined in terms of the tympanic crest. Dean and Wood defined tympanic angle differently again (Dean & Wood 1981:64,65)].

(17) Relative Orientation of Tympanic and Petrous Axes. The angle between the petrous and tympanic axes is more acute

in *H.erectus* than in modern humans and even more acute in apes. Weidenreich found the following angle ranges: modern humans, 150°–180°; Sinanthropus IIIE, 140°; Ngandong, 120°–135°. this trend is consistent with the change in the tympanic sagittal inclination noted in Tympanic Orientation, above, and also corresponds closely to the increase in the petrous pyramid sagittal angle from apes to *H.erectus* to modern humans. Weidenreich saw these differences as corresponding to a reduction in length and robustness of the petrous and tympanic in the course of evolution (Macintosh & Larnach 1972:3,5; Larnach & Macintosh 1974:97; Rightmire 1990:94; Weidenreich 1943:57,58,203,204; 1951:278). Aiello and Dean (1991:69–71), and Dean and Wood (1982:161,162,168) considered a more acute petrous angle consistent with a long narrow cranial base and posteriorly placed foramen magnum, as seen in apes. Weidenreich described the increased petrous angle as a consequence of the "rolling up of the braincase" about an inter-porion axis (Weidenreich, 1943:58). Stringer thought an increase in the petrous-tympanic angle similarly may be related to the shortening and flexion of the cranial base, e.g. from *H.erectus* to modern humans, which in turn corresponds to changing orientation of the face in relation to the vault (Stringer 1984:135,137).

(18) Thickness of the Tympanic Plate. In accordance with the general thickness of *H.erectus* cranial bone, the tympanic plate is much thicker than in modern humans. If robustness is retained in the modern human tympanic, Weidenreich notes, it is confined to the lateral margin as localised hyperostosis of the bone, as for example in Eskimos and some Amerindians. The tympanic plate of anthropoids, while thicker than that of modern humans is not as extreme as that of *H.erectus* except perhaps at the lateral edge (Rightmire 1990:151,177,236; Weidenreich 1943:54,202,203).

(19) Curvature of the Tympanic Plate. For modern humans the anteromedial inferior surface of the tympanic plate is described as concave and concordant with the curvature of the glenoid fossa. By contrast, the corresponding surface in Asian *H.erectus* is described as straight or convex, resembling the condition in anthropoids. Weidenreich attributes this to the reduction of tympanic thickness, particularly medially, in modern humans (Larnach & Macintosh 1974:100; Weidenreich

1943:53,54,202,203; 1951:275).

(20) Petrosal (Tympanic) Crest. This feature, the posterior edge of the tympanic plate, is described by Weidenreich as "massively" thick in *H.erectus* and a striking contrast to the uniformly thin, blade-like edge seen in modern humans. In anthropoids the crest is low and rounded (Rightmire 1990:177,189; Weidenreich 1943:59,204; 1951:275).

(21) "Processus Supratubalis". This feature is recognised in African and Asian *H.erectus*. Initially, Weidenreich (1943:61,204) defined it for *Sinanthropus* as "a small, round, tuber-like elevation which marks the medial *anterior* end of the tympanic plate...a distinct swelling". He observed it in Skull IIIE, judged it to be "broken off" in all other Sinanthropus crania and observed it present and even more pronounced in Ngandong crania. (The region is damaged in *Pithecanthropus*). Rightmire (1990:177,189) included "process supratubarius" among *H.erectus* traits, but described it as the "blunt tubercle" medially terminating the tympanic plate.

In anthropoids, the process is present, sharply pointed and projects extensively, leaning against the entoglenoid process to which it is attached at the base. It exists in modern humans, representing the termination of the petrosal crest as a fine spine-like projection (Rightmire 1990:44,94, 151,152,189; Santa Luca 1980:108; Weidenreich 1943:61,204, Figs.121-123; 1951:276,277).

(22) Zygomatic Root Overhang of External Auditory Meatus Measuring the overhang as the difference between auriculare and the most lateral point of the external auditory meatus, Weidenreich found that in modern humans the overhang is less than 10mm., for Asian *H.erectus* it is approximately 10-15mm., while the tympanic plate of the gorilla may protrude even more laterally than auriculare (Weidenreich 1943:52,202; 1951:275).

(23) Transverse Lateral Slit. In *Sinanthropus* Skull IIIE only[1] there exists a lateral transverse slit on both tympanic

[1] A comparable structure arguably exists in the adult *Sinanthropus* Skull XI, but could be explained as merely a damaged tympanic edge. It is not possible to judge from a cast and Weidenreich's drawings alone.

plates which divides each external auditory meatus edge into anterior and posterior lobes (Fig.3.3.1a). Weidenreich saw this as an infantile character; he equated it with the foramen of Huschke in modern humans, which usually disappears by the 5th.year but may continue through life (Fig.3.3.1b). If so, IIIE is (i) $\leq$5 years, (ii) $>$ 5 years but the age of closure is later in *H.erectus* juveniles than in modern humans, or (iii) $>$ 5 years but the feature has been retained into adolescence or adulthood (Weidenreich 1943:54,55,180,203; 1951:276).

However, it seems more likely that the *H.erectus* lateral slit corresponds to a second type of tympanic plate aperture which occurs in modern humans, the marginal groove, canal or foramen (Fig.3.3.1c), a feature which does not appear until puberty when the full lateral growth of the plate is complete (Hauser & De Stefano 1989:143). In that case, Skull IIIE is adolescent or adult. Weidenreich (1943:180) associated Skull IIIE with an 8 or 9 year old, Davidson Black with an early adolescent. No conclusion can be drawn about the frequency of the condition in *H.erectus* from only one case, but it does show that the deficiency is not dependent on the tympanic plate being thin.

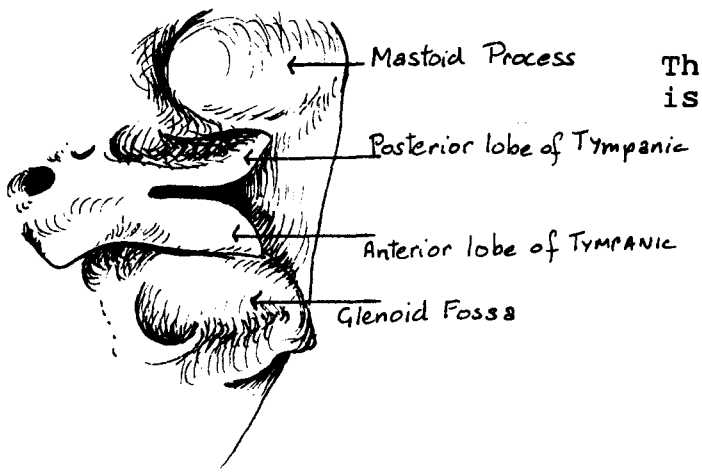
8.1.1.5 PETROUS PYRAMID

(24) Orientation of the Petrous Pyramid: Endocranial Aspects. The endocranial surface of the petrous pyramid in *H.erectus* is lower and flatter than in modern humans. The meeting edge of the superior and posterior surfaces is rounded and the posterior surface slopes gradually to the cranial floor in *H.erectus*; in modern humans the same edge is sharp and overhangs the posterior surface which is more vertical or even slopes anteriorly to the cranial floor. The same difference, but to less extent, is true of the petrous anterior surface. In anthropoids, especially gorilla, the petrous pyramid is also flat and pressed against the cranial floor for a considerable distance (Figs.8.1.1 & 2).

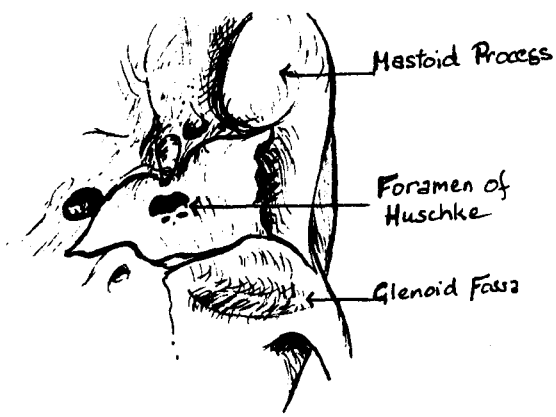
Cerebellum expansion from *H.erectus* to modern humans may be a factor in this change in the endocranial petrous surface. The anterior surface of the cerebellum in modern humans contributes to the shape of the endocranial posterior surface of the petrous, lateral of the internal auditory meatus. It forms a distinct fossa, often deep and inclusive of the

Fig.8.1.1 APERTURES IN THE FLOOR OF THE EXTERNAL ACOUSTIC MEATUS

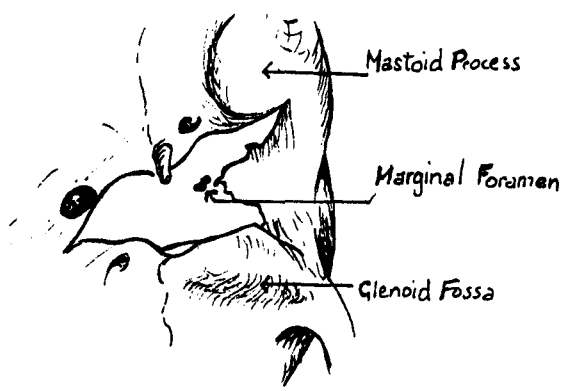
The right Tympanic region is depicted for *H.erectus* and Modern Humans. BASAL VIEW.



a) *H.erectus* [*Sinanthropus* Skull IIIE] (after Weidenreich 1943:377, Fig.103)

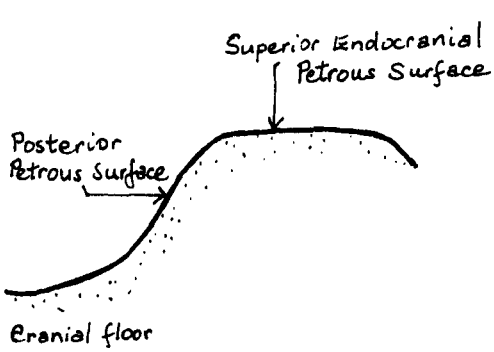


b) Modern Human, adult.

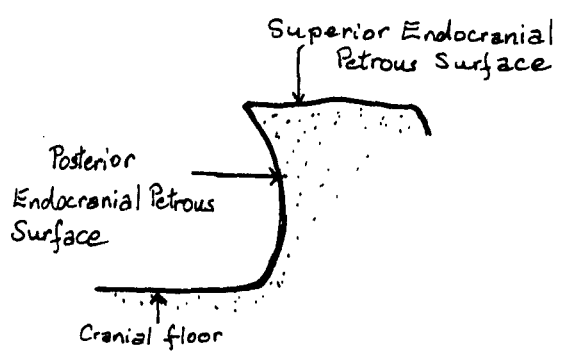


c) Modern Human, adult.

Fig.8.1.2 ENDOCRANIAL PETROUS SHAPE



a) *H.erectus*



b) Modern Human

sigmoid sulcus, thus accounting for the overhanging posterior-superior petrous edge. In *H.erectus*, the posterior petrous surface tends to be smaller; it may be slightly impressed but is more likely to bulge backward; the sigmoid sulcus is much narrower and shallower in *H.erectus* than in modern humans. (As for modern humans, the right sigmoid sulcus in *H.erectus* is larger than the left) (Weidenreich 1943:67,68,206; 1951:286).

Weidenreich linked the change in the endocranial petrous surface to the shortening of the cranial base, which forces the pyramid upwards and shortens its sagittal dimensions (Weidenreich 1943:67). The forward migration of the foramen magnum and shortening of the basioccipital have been suggested as factors in compressing the cerebellum into the posterior portion of the petrous (Aiello & Dean 1990:169).

Since differences in petrous orientation between apes and modern humans exist at or before birth, Dean concluded that the underlying cause of the differences must occur in foetal development (Dean 1988:108). He points out that the huge acceleration in the development of the cerebellum compared to the rest of the brain between the 13th. week of gestation and the 2nd postnatal year in modern humans means that the cerebellum expands faster than the posterior part of the cranial base can elongate. This forces the cerebellum to expand laterally and results in the compression of the petrous bone such that it becomes more coronally orientated, at least in endocranial aspect, and its posterior surface becomes more vertical. In apes, the basioccipital bone is faster growing and so relatively longer; this allows the cerebellum to expand posteriorly rather than laterally and consequently the petrous bone is less coronally oriented than in modern humans (Dean 1988:108-110).

If the external and endocranial orientation of the petrous axis correspond, then cerebellum expansion is a major factor in also determining the external orientation of the petrous and petrous-tympanic angles, although other factors may be involved externally. Using high resolution CT techniques, Spoor found that the endocranial orientation of the petrous pyramid does <u>not</u> correspond to the external orientation and the orientation of the bony labyrinth in *H.erectus* (Sangiran 2 & 4 and OH9) is not significantly different to that of modern humans (Spoor 1992:1,5).

8.1.1.6 OCCIPITAL

In addition to the 25 temporal bone features discussed above, some occipital features are also considered because of their possible links to important temporal traits.

(25) Occipital Curvature. *H.erectus* occipital is strongly flexed; the curvature is much greater than in modern humans, mainly because of the prominent occipital torus in *H.erectus* (Rightmire 1984:83; 1990:176; Weidenreich 1943:39; 1951:257).

(26) Ratio of Cerebellar to Cerebral Fossae Area. The cerebellum is less developed in *H.erectus* than in modern humans and Weidenreich found that cerebellar to cerebral fossa area in Sinanthropus is approximately 3:4, whereas in modern humans the ratio is approximately 4:3. Expansion of the cerebellum and corresponding increase in the cerebellar fossae, while the cerebral fossa does not increase, has resulted in the lengthening of the distance between the internal occipital protuberance and opisthion in modern humans compared to *H.erectus*. The anthropoid condition is similar to *H.erectus* (Weidenreich 1943:40-2).

(27) Ratio of Upper to Lower Occipital Sagittal Chords. Based on the ratio of lambda-inion chord to inion-opisthion chord, Weidenreich found that the upper plane is larger than the lower plane in modern humans. In *H.erectus*, either the lower plane is larger or, as in Ngandong, the upper to lower plane ratio is less than in modern humans. (Weidenreich 1943:38,39;1951:255). The definition of inion used in a particular study needs to be noted since it affects ratio values (Hublin 1978:65; this study, Section 4.2 Appendix Tables A.4.7 & 8). As nuchal muscles decreased in size and the total brain size increased, the nuchal plane became smaller, the occipital plane larger and inion moved closer to opisthion.

(28) The Separation between Inion and Endinion. Inion in *H.erectus* is located higher on the cranium than endinion, whereas in modern humans inion is reported as being at the same or slightly lower level than endinion (Weidenreich 1943:40;1951:267). As with occipital chord ratio, inconsistencies in the definition of inion should be taken in to account.

8.1.1.7 SUMMARY: TEMPORAL BONE ANATOMY OF *H.ERECTUS*

1] For most of the traits, the *H.erectus* character state compared to that of modern humans represents the more primitive condition, since the *H.erectus* form is either similar to that of the outgroups, *Gorilla* and *Pan*, or intermediate between them and modern humans. In this category are the following features:

1. Temporal Squamous Height
2. Temporal Squamous Shape
3. Supramastoid Crest
4. Suprameatal Crest Angle
5. Glenoid Fossa Size,Shape
6. Entoglenoid Process
10. Mastoid Shape
11. Mastoid Orientation
15. Tympanic Vert./Horiz. Orientation
16. Tympanic Sagittal Orientation
17. Petrous-Tympanic Angle
19. Tympanic Plate Curvature
24. Petrous Endocranial Shape
26. Cerebellar:Cerebral Fossa Area
27. Upper/Lower Occipital Chord Ratio
28. Endinion-Inion Separation

2] For some traits, the variation in expression exhibited by *H.erectus* is less than and within the range of modern human variation: 8. Postglenoid Process 9. Mastoid Size
13. Digastric Groove 23. Transverse Lateral Slit

3] Of the traits considered and on the evidence provided, only these few are possible autapomorphs of *H.erectus*:

7. Medial (Entoglenoid/Tympanic) Recess
14. Mastoid Fissure
18. Thickness of the Tympanic Plate
20. Thick Petrosal (Tympanic) Crest
21. Supratubalis Process
25. Occipital Curvature
28. Separation between Inion and Endinion

Thick petrosal crest and supratubalis process can be seen as two manifestations of general tympanic plate robustness rather than as separate traits. Also, it is not clear whether the form of the supratubalis process in *H.erectus* is proposed as merely intermediate between the ape and modern human conditions or as an expression unique for *H.erectus*.

8.1.2 POSSIBLE AUTAPOMORPHIC TEMPORAL FEATURES OF HOMO ERECTUS

8.1.2.1 Proposed Autapomorphic Temporal Traits for *H.erectus*.

In order to compile a list of traits unique to *H.erectus* (autapomorphs) which could be used to define the taxon, a number of authors evaluated the cranial features used in the literature to describe *H.erectus* (Andrews 1984; Rightmire 1990; Stringer 1984; Wood 1984). Some inconsistencies remain with regard to trait definitions and whether or not African specimens attributed to *H.erectus* and/or the Ngandong fossils should be included with Asian *H.erectus* in establishing a set of *H.erectus* autapomorphs.

Of the features suggested as autapomorphic for *H.erectus*, those concerning the temporal bone are listed below, together with 3 occipital traits with possible temporal links.

PROPOSED AUTAPOMORPHIC *H.ERECTUS* TEMPORAL TRAITS	AUTHOR *
1. Mastoid Fissure separating the mastoid process from the petrosal crest of the tympanic. (Asian only)	A,S
2. Extremely thick tympanic plate. (Asian only)	A,S
3. Strong petrosal crest terminating in a blunt supratubalis.	R
4. A deep recess between the tympanic plate and entoglenoid process. A sphenoid spine is not part of the entoglenoid process.(Asian & African)	R,A
PROPOSED AUTAPOMORPHIC *H.ERECTUS* OCCIPITAL TRAITS (*values for nos.5 & 7 depend on inion definition)	AUTHOR
5. Inion and endinion are well separated (inion higher than endinion). (Asian; African unknown)	A,S,W
6. Sharply flexed occipital surface; small occipital chord to arc ratio. (Asian & African)	R,W, *S
7. Low ratio of occipital plane length to nuchal plane length. (Asian & African)	W,*S

* AUTHORS:

A = Andrews 1984:170,173-5. R = Rightmire 1990:189; 1989:90,96

S = Stringer 1984:134,135 (*S autapomorphic for Asian *H.erectus* only)

W = Wood 1984:105-107.

Andrews and Stringer found no grounds for combining African specimens attributed to *H.erectus* with the more specialized Asian *H.erectus*, since the common features shared by the two groups are retained primitive retentions (symplesiomorphs) (Stringer 1984:141).

Stringer recognises a "concentration of derived characters" unique to Asian *H.erectus* which excludes it as an ancestor of modern humans (Stringer 1984:141). Rightmire considers *H.erectus* as one world-wide species and the differences between African and Asian *H.erectus* crania as no more than expected for such a wide geographic range (Rightmire 1990:179). Kramer came to the same conclusion, finding no Asian *H.erectus* autapomorphies from craniometric evidence (Kramer 1993:161-170). Hublin regards the mastoid fissure and the tympanic robustness as regional characteristics of Asian *H.erectus* and found no derived traits unique to the combined African-Asian *H.erectus* sample (Hublin 1985:286,287).

8.1.2.2 Assessment of Proposed Autapomorphic Temporal Traits for *H.erectus*

Of the 7 traits suggested in the Table above as *H.erectus* autapomorphs, 2 temporal (mastoid fissure and glenoid fossa medial recess) and 1 occipital (inion-endinion separation) were among a group of traits examined in a study by Brauer & Mbua to test the validity of several proposed *H.erectus* autapomorphs (Brauer & Mbua 1992:79-108). The same three traits and a fourth, tympanic plate thickness, were also among a dozen traits tested in an earlier study by Kennedy (Kennedy, 1991:375-412).

Brauer and Mbua made the important observation that of the features they evaluated as potential *H.erectus* autapomorphs, all show continuous variation. Hence, to treat them as discrete character states which are either present or absent is inappropriate (Brauer & Mbua 1992:79,80,105).

INION-ENDINION SEPARATION: As pointed out in both studies, the lack of standardization in measuring method and in the definition of inion makes comparison of data from different sources hazardous. In Kennedy's study, quantitative data for this characteristic were compared for modern humans (N=30), *Gorilla* (N=3), *Pan* (N=6), 17 Asian *H.erectus* and several other fossil hominids. (Direct measurements were used for modern humans, apes and a few non-*H.erectus* fossils. All other measurements were quoted from the literature.) In the direct measurements, the separation was found by subtracting endinion-opisthion length from inion-opisthion length (Endinion as defined by Weidenreich 1951:267, inion as defined by Martin 1928:615). Kennedy established that the primitive polarity for this trait is for inion higher than endinion. Although 63.3% of the modern human sample had inion above endinion, the separation was small compared to that of *H.erectus*, australopithecines and apes. Kennedy concluded that the location of inion above endinion is a general symplesiomorphic feature of apes and of recent and fossil hominids, including *H.erectus*. (Kennedy 1991:397-400).

Brauer and Mbua analyzed data for 16 Asian and 5 African *H.erectus*, 6 African early Homo, 3 Archaic *H.sapiens* and 4 Australopithecines. Most of the Asian *H.erectus* as well as African ER3733, 3883 and OH9 have inion well above endinion (≥

18mm). However, Brauer & Mbua noted wide variation across the values of Asian *H.erectus* and the African groups, and considering also the functional complexity of the measurement, they discounted inion-endinion separation as a useful *H.erectus* autapomorphic feature. Data for apes and modern humans were not included. (Brauer & Mbua 1992:97,98,105)

MASTOID FISSURE: Kennedy treated this as a discrete character state, recordable as present or absent on a particular skull. From the literature, she noted it was found as present in Asian *H.erectus*, absent in African hominids attributed to *H.erectus*, and inconclusive in australopithecines. From her own observations, Kennedy judged it present in *Gorilla*, unable to be assessed in *Pan* (undeveloped mastoid process), and variable in Neanderthal. In a modern human sample of 50 Poundbury crania, she observed the mastoid fissure present, though "rare and small", 10% having a "crevice" < 1mm. "between the tympanic and mastoid". Kennedy concluded the trait could not be a *H.erectus* autapomorph (Kennedy 1991:400,401).

Brauer and Mbua considered the feature poorly defined, and unable to be simply standardized. The fissure can be easily distorted and shows considerable variation in expression. Nevertheless, they judged the mastoid fissure present in all Asian *H.erectus* where it could be assessed except Sangiran 17, absent in the African specimens attributed to *H.erectus* except for OH12, present in at least one australopithecines, present in early *Homo* and present in 2 of 5 archaic *H.sapiens*. Consequently, Brauer and Mbua also concluded the feature cannot be regarded as a *H.erectus* autapomorph (Brauer & Mbua 1992:99,100). The results of both studies further suggest the presence of a mastoid fissure is most likely symplesiomorphic.

GLENOID FOSSA MEDIAL RECESS: As for the mastoid fissure, it is both difficult to establish a precise, standardized definition of this trait which is so variably expressed, and misleading to evaluate it as a discrete character state. Kennedy judged the medial recess between the entoglenoid process and the tympanic plate as a symplesiomorphic trait. From the literature, Kennedy noted that the medial recess is

present in Asian and African *H.erectus*, early Homo and australopithecines. Andrews had said the recess is absent in African apes (Andrews 1984:175). However, from her own observations, Kennedy found it present in *Gorilla* (always wide), in *Pan* (highly variable), and also in Neanderthals. In the sample of 50 Poundbury modern humans, Kennedy found the usual pattern is of an entoglenoid process with inferiorly projecting sphenoid, "usually" overlapping the tympanic plate and "usually" with a narrow (<1mm.) recess or fissure between the process and the tympanic plate.

Brauer and Mbua noted extreme variability in width and depth of the recess, even between the left and right sides of the one cranium. They found the recess present in australopithecines, in 1 of 3 early *Homo*, all 3 African *H.erectus*, most but not all Asian *H.erectus*, and some but not all archaic *H.sapiens*. They concluded that the glenoid fossa medial recess must be a symplesiomorph. It cannot be regarded as uniquely derived for Asian *H.erectus*, nor as a shared derived feature for African and Asian *H.erectus*.

In both studies it was thought there may be inter-correlation between the medial recess and the mastoid fissure. Kennedy (1991:403) suggested they may be related to cranial base flexion. Weidenreich (1943:47) had linked the recess to the anteroposterior compression of the fossa.

TYMPANIC PLATE THICKNESS: Kennedy found that the greater thickness of the *H.erectus* tympanic plate relative to that of modern humans is symplesiomorphic, and part of the general symplesiomorphic thickness of the temporal bone. Using the midpoint of the free lateral tympanic margin as a measure of thickness, a quantitative comparison was made between modern humans, *Pan* and *Gorilla*, and several hominid fossils. But assessment of the condition in *H.erectus* depended on qualitative reports in the literature for African and Asian representatives (ER3733, ER3883, OH9, Sangiran 2). Kennedy concluded that the tympanic plates of *H.erectus* and apes are comparably thicker than that of modern humans; in both apes and *H.erectus*, increase in spongy bone is the cause, whereas tabular bone is found at the lateral margin in modern humans. (Kennedy 1991:387-390,405).

8.1.2.3 SUMMARY: *H.ERECTUS* AUTAPOMORPHIC FEATURES

(i) *H.ERECTUS* AUTAPOMORPHIC TRAITS EVALUATED

From the evaluation of proposed *H.erectus* autapomorphs, both studies (Kennedy 1991 and Brauer & Mbua 1992) concluded that none of the investigated traits could be accepted as uniquely derived for Asian *H.erectus,* or shared-derived for African and Asian *H.erectus.* Kennedy, Brauer and Mbua considered that the temporal traits, mastoid fissure, medial glenoid fossa recess, and the occipital trait, inion placed well above endinion, are symplesiomorphs. Kennedy reached the same conclusion about *H.erectus* tympanic plate thickness.

However, there is need for more precise definitions of the mastoid fissure and the medial recess. The continuous nature of the variation the features show in population groups and which Brauer and Mbua themselves highlight (Brauer & Mbua 1992:80) should be taken into account in assessing the presence or absence of the feature. For example, what size gap qualifies as a mastoid fissure or medial recess, and in what way exactly is it to be measured?

(ii) IMPORTANCE OF NON-AUTAPOMORPHIC H.ERECTUS TRAITS:

Wood holds that although the definition of a taxon should include all its autapomorphs, yet it is not limited to only those autapomorphs. The group's primitive-retained and shared-derived traits, individually, are not unique to the group, but the combination of such traits may be (Wood 1984:104;1991:38).

Although none of the features considered have been found to be unique for *H.erectus* and so cannot be used to define the group as a taxon, nevertheless, most of the features, individually or as a combined suite of traits, are useful in distinguishing H.erectus, e.g. from modern humans (Rightmire 1984:96, 1990:186-190).

Hence for such a set of features associated with *H.erectus,* a detailed assessment of their manifestation in modern human groups representing major geographical regions may reveal differences between the groups which have important implications concerning the origins of modern man.

8.2 TRACING *H.ERECTUS* TRAITS IN MODERN HUMANS

8.2.1 INTRODUCTION, PURPOSE AND PROCEDURE

8.2.1.1 INTRODUCTION

Both Rightmire (1990:186,190) and Wood (1984:104;1991:38) have stressed that whether or not individual traits of *H.erectus* prove to be uniquely derived they may still be important, individually or combined with other traits, in distinguishing *H.erectus* from or linking *H.erectus* to other hominids, e.g. *H.sapiens* or even a specific regional group within *H.sapiens*. For instance, do any such features associated with Asian *H.erectus*, occur more frequently or more clearly in Australian and/or Chinese crania than in crania from other major geographical regions? Brauer and Mbua (1992:106) endorse the importance of examining the occurrence and variability of descriptive traits to determine the polarities of morphological patterns and thereby assist understanding of evolutionary differentiation and transitions e.g.of *H.erectus* to archaic *H.sapiens*.

If it could be shown that Asian *H.erectus* differ significantly from African *H.erectus* in one or more traits,

a) there would be support for the multiregional origin of modern humans if it could further be shown that modern Australian and/or Chinese crania are more similar in those characteristics to Asian *H.erectus* than are modern human crania from other regions.

b) support for a multiregional origin would be weakened, and a replacement theory supported if it could further be shown that modern crania including Australian and Chinese crania are more similar in those characteristics to African than to Asian *H.erectus*, particularly if there is a significant difference in those traits between Asian *H.erectus* and modern humans. Whichever is the derived character state, Asian *H.erectus* would be unlikely as a modern human ancestor.

c) a multiregional origin would be unlikely and a replacement theory supported if one or more features could be shown to be uniquely derived for Asian *H.erectus* and not similarly expressed in modern Australian or Chinese crania.

8.2.1.2 PURPOSE

A number of the features reviewed in Section 8.1 as suggested characteristic and possibly autapomorphic features of *H.erectus* are examined with regard to their expression in modern humans generally and in specific modern groups, and compared to the expression of those features in Asian and African *H.erectus* and African apes. The investigation seeks to establish if the features are either (i) autapomorphs for Asian *H.erectus* or (ii) continuity features in East Asia and/or Australasia. Answers to the following questions are sought:

*Is the feature unique and derived for Asian *H.erectus*?

*Is the feature shared and derived for Asian and African *H.erectus*?

*Do modern Australian and/or Chinese groups show greater similarity to the Asian *H.erectus* expression of the feature than do other modern groups?

*If differences in the feature between species appears to be merely a gradual modification, in which modern human group is the primitive polarity most evident?

*Is the expression of the feature predominantly a function of another characteristic (e.g.cranial size) within modern humans and/or across species boundaries?

8.2.1.3 PROCEDURE

CRANIAL SAMPLES: For comparative purposes, several features were examined in a small cranial sample of African apes, a number of casts of Asian and African fossils attributed to *H.erectus* and 3 terminal Pleistocene fossils as well as in a sample of recent modern humans. The ape crania are from the Anthropology Department, University College London, all other specimens are from the Natural History Museum London.

1) RECENT MODERN HUMANS: 280 crania from 6 populations of 6 major geographic regions (The NHM specimens listed in Appendix Table A.4.4). Andamanese (44) Australian (51) Chinese (44) Eskimo (42) Gabon (50) Poundbury (49)

2) APES: 3 *Gorilla* (2 male and 1 female), 4 *Pan* (Appendix Table A.8.2)

3) *H.ERECTUS*: Casts of 16 Asian and 4 African fossils attributed to *H.erectus*: (Table A.8.1)

AFRICA OH9, OH12, ER 3733, ER 3883.
CHINA Zhoukoudian IIIE,V,X(L1),XI(L2),XII(L3).
JAVA Sangiran 2, 4, 10, 17, Sambungmacan 1.
Ngandong 1, 6, 7, 10, 11, 12.

4) AUSTRALIAN MODERN HUMAN FOSSILS (Terminal Pleistocene):
Kow Swamp 5 (13.0 ka ago (Brown 1993:220,1989:6))
Kanalda (undated, but morphologically similar to Coobool Creek material dated at 14.3 ka ago (Brown 1993:220))

Because of incomplete preservation, not all features are available for observation on all fossil casts; e.g. OH12 could be used for only 4 features.

FEATURES INVESTIGATED: [* not specified in previous lists]

[A] DESCRIPTIVE	temporal squamous height
mastoid fissure	tympanic medial curvature
medial recess	foramen of Huschke
supratubalis process	*tegmen tympani
[B] QUANTITATIVE	
tympanic rim thickness	mastoid depth
EAM "overhang" or indent	glenoid fossa depth
suprameatal crest angle	glenoid fossa area
petrous sagittal angle	glenoid fossa volume
tympanic sagittal angle	glenoid fossa length-width ratio
petrous-tympanic angle	endinion-inion separation
internal petrous angle	occipital curvature
upper/lower cranial breadth ratio	nuchal/occipital sagittal chord ratio

Most of the features considered are clearly quantitative and have been assessed accordingly (Section 8.2.3.1-18). Some features have generally been treated in other studies as discrete character states and as most appropriately assessed by merely recording presence or absence. However, as Brauer and Mbua (1992:80) pointed out about the features they assessed, supposed descriptive traits can show continuous variation in expression. Consequently, a limited quantitative treatment appropriate to each "descriptive" trait investigated in this study is incorporated in its assessment and is outlined for each feature in the following discussion.

8.2.2 DESCRIPTIVE FEATURES

8.2.2.1 MASTOID FISSURE:

The distinction needs to be made between a true mastoid fissure and a crevice or crack, of varying depth and width. The latter quite often occurs between the anterior side of the mastoid process and the posterior lateral tympanic wall of the external acoustic meatus, -- not the petrosal crest. The mastoid fissure is defined by Santa Luca, and accepted by Andrews and Stringer, as the fissure which "separates the mastoid process from the petrosal crest"... and that it is absent in modern humans because "the petrosal crest fuses with the anteromedial edge of the mastoid process" (Santa Luca 1980:108; Andrews 1984:174; Stringer 1984:134). A true mastoid fissure and a crevice may or may not exist together.

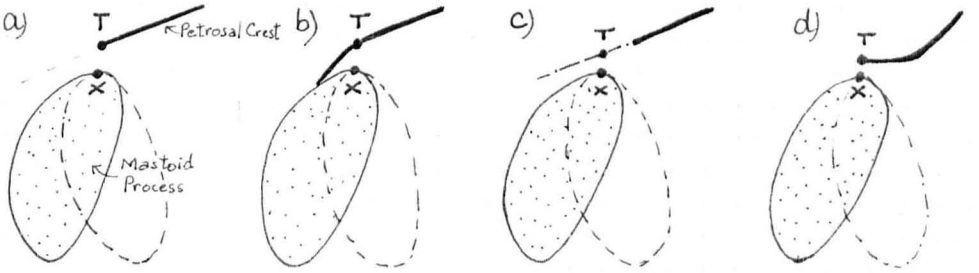
It was found that extreme variation exists in the way the tympanic petrosal crest meets or does not meet the anterior region of the mastoid process in modern humans. However, it is feasible to categorize the variation into 7 possible cases when crania are viewed in norma basalis. These are represented in Fig.8.2.1.1(a-g), which depict the relative positions of tympanic petrosal crest and anterior of the mastoid process as viewed from norma basalis. The presence of a mastoid fissure is indicated in Figs.8.2.1.1(a-d) which show a gap between the most anterior point of the mastoid process, X, and the petrosal crest or, as in Fig.8.2.1.1(c), the lateral extension of the crest. Absence of the mastoid fissure is represented in Figs.8.2.1.1(e-g) which show the tympanic petrosal crest (or as in Fig.8.2.1.1(g), the lateral extension of the crest) meeting the mastoid process at or medial to its most anterior point.

Examples of mastoid fissures present in apes, *H.erectus* and modern humans are pictured in Plate 8.1.

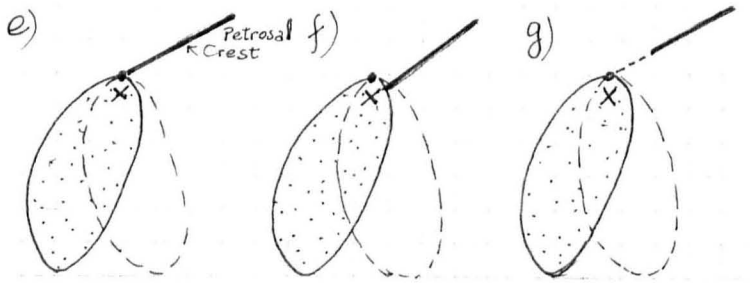
The width of the mastoid fissure was measured using the dial callipers and/or the feeler gauge, and is indicated in Figs.8.2.1.1.a-d, by TX, a line which is parallel to the sagittal line. The approximate depth of the fissure was also noted as shallow, medium or deep. On a few crania, no petrosal crest is evident lateral of the styloid process; in such

Fig.8.2.1.1 MASTOID FISSURE [BASAL VIEW]

Lateral Approach of the Tympanic Petrosal Crest to the Anterior Point of the Mastoid Process.



A Mastoid Fissure is present in Cases a-d, absent in Cases e-g

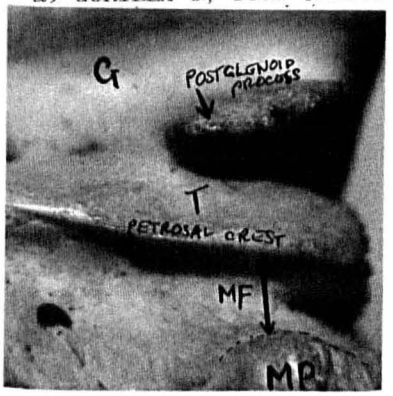


X = most anterior point on mastoid process
T = point on tympanic crest anterior to X
TX = MASTOID FISSURE width, parallel to sagittal line

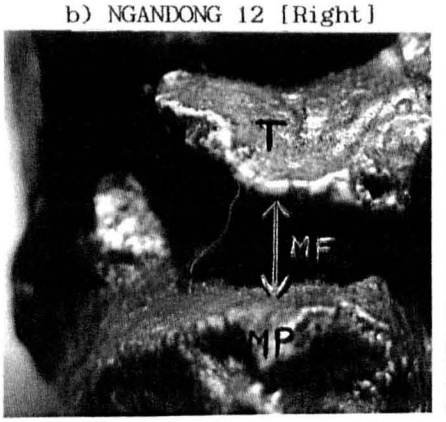
Plate 8.1

MASTOID FISSURE IN APES, *H.ERECTUS* AND MODERN HUMANS

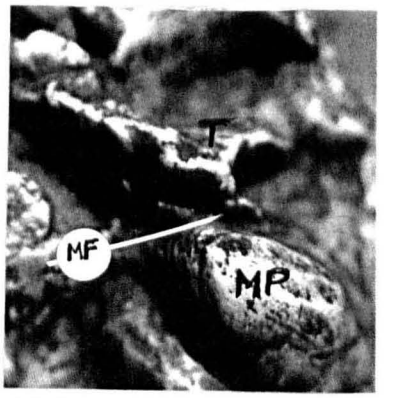
a) *GORILLA* ♂, 1192 [Left]



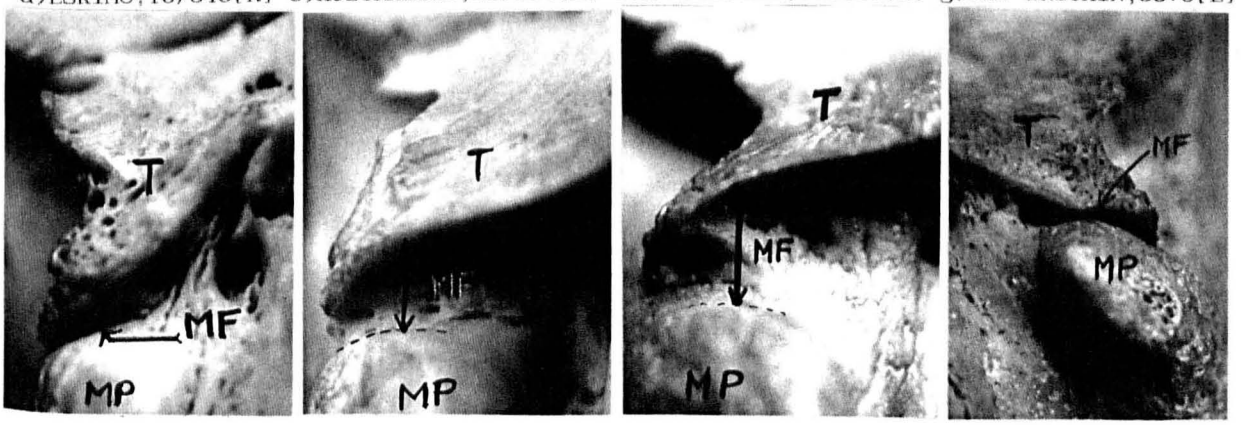
b) NGANDONG 12 [Right]



c) SANGIRAN IV [Left]



d)ESKIMO,10/840[R] e)AUSTRALIAN,30/984[R] f)ANDAMANESE,8.0330[R] g)NEW BRITAIN,3370[L]



G=glenoid fossa; MP=mastoid process; MF=mastoid fissure; T=tympanic plate

cases, the mastoid fissure has been recorded as absent.

In Table 8.1. the following results are recorded for both left and right sides:

*Percentage occurrence of the Mastoid Fissure ≥ .25 mm.wide;
*Percentage occurrence of the Mastoid Fissure ≥ 1.0 mm.wide;
*Percentage absence of the Mastoid Fissure;
*Percentage absence of the Petrosal Crest lateral of the Styloid Process.

Whether the minimum width of the mastoid fissure is taken as .25mm. or 1.0mm., it is present most frequently in Gabon, Eskimo and Andamanese (50-68% if fissure >.25 mm., 34-58% if fissure >1.0mm.) (Table 8.1). The lowest percentage occurrence is in Poundbury (6.1-8.2% if fissure >.25 mm., 4.1-8.2% if fissure >1.0mm.). This is in good agreement with the result of Kennedy's examination of 50 Poundbury crania; she found the fissure present in 10%, though never wider than 1mm. (Kennedy, 1991:401). From this result she was able to conclude that the mastoid fissure does occur, if infrequently, in modern humans. The results of this study support that conclusion but further show that the mastoid fissure is approximately 4 times more common in modern humans than would be deduced from investigation of a sample of Poundbury crania alone (26.8-33.2% frequency if fissure ≥1mm., 38.3-39.8% frequency if fissure ≥.25mm. (Table 8.1)).

Mastoid fissure depth in modern humans is variable within the total sample and between groups. Deep fissures occur but are not common in any group. Andamanese have a predominance of shallow fissures; Gabon and Eskimo crania show the greatest variability in fissure depth. For 5.7% of the total sample no petrosal crest is evident lateral of the styloid process (Table 8.1).

In the ape sample, all 3 *Gorilla* crania have deep mastoid fissures (Table 8.3); the *Pan* crania could not be assessed for the condition since the mastoid anatomy involving a non-projecting process precludes the possibility of a mastoid fissure as defined.

From the 20 casts of fossils attributed to *H.erectus*, 6 could not be assessed conclusively for the condition (Table 8.3). The fissure is absent on ER3883, the only assessable

TABLE 8.1 OCCURRENCE OF MASTOID FISSURE IN MODERN HUMANS

		AND	GAB	AUS	CHI	POU	ESK	TOTAL
MAST.FISSURE ≥ 1.0mm.	L	34.1%	50.0%	8.0%	18.2%	4.1%	50.0%	26.8%
	R	41.7%	58.0%	12.0%	25.0%	8.2%	52.4%	33.2%
MAST.FISSURE ≥ .25mm.	L	50.0%	64.0%	25.6%	31.8%	6.1%	57.1%	38.3%
	R	56.8%	68.0%	21.6%	34.1%	8.2%	57.1%	39.8%
NO MASTOID FISSURE	L	43.2%	24.0%	66.0%	65.9%	93.9%	38.1%	55.7%
	R	34.1%	22.0%	70.6%	63.6%	91.8%	35.1%	53.9%
NO PETR.CREST LATERAL OF STYL.PROC.	L	6.8%	12.0%	7.8%	2.3%	0.0%	4.8%	5.7%
	R	9.1%	8.0%	7.8%	2.3%	0.0%	7.1%	5.7%
DEPTH S=shallow	L	30% S	20% S	12% S	4.5%S	2% S	29% S	16% S
	R	23% S	14% S	10% S	6.8%S	2% S	31% S	14% S
D=deep	L	0% D	14% D	2% D	10% D	2% D	12% D	6.4%S
	R	0% D	18% D	2% D	10% D	2% D	7.1%D	6.4%S
SAMPLE SIZE		44	50	51	44	49	42	280

TABLE 8.2 OCCURRENCE OF MEDIAL RECESS IN MODERN HUMANS

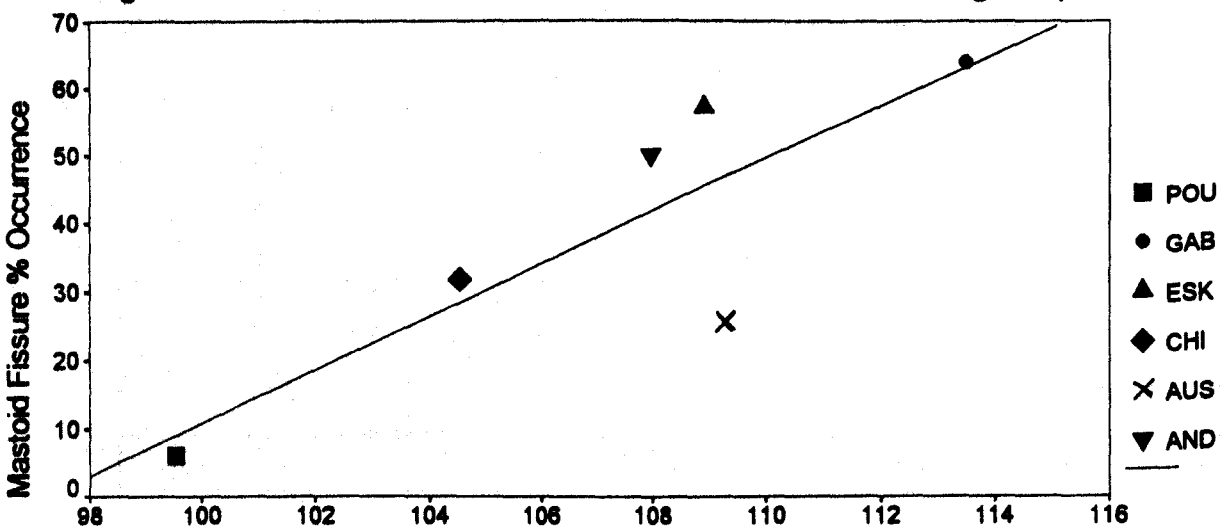
		AND	GAB	AUS	CHI	POU	ESK	TOTAL
MEDIAL RECESS ≥ 1.0mm.	L	6.8%	8.0%	2.0%	11.4%	6.1%	9.8%	7.5%
	R	6.8%	8.0%	2.0%	11.4%	8.2%	9.8%	7.9%
≥.5mm. & < 1.0mm.	L	4.5%	28.0%	3.9%	29.5%	18.4%	43.9%	20.7%
	R	9.1%	22.0%	5.9%	29.5%	24.5%	39.0%	21.1%
≥.1mm. & < .5mm.	L	11.4%	20.0%	11.8%	29.5%	51.0%	17.1%	23.6%
	R	13.6%	12.0%	15.7%	31.8%	46.9%	17.1%	22.9%
NO MEDIAL RECESS	L	77.3%	44.0%	82.4%	29.5%	24.5%	29.3%	48.2%
	R	70.5%	48.0%	76.5%	27.3%	20.4%	34.1%	48.2%
SAMPLE SIZE		44	50	51	44	49	42	280
EP.SPINE SIZE > 5mm.	L	45.5%	24.0%	56.0%	61.4%	68.8%	73.8%	54.3%
	R	50.0%	28.0%	52.0%	65.9%	66.0%	69.0%	54.3%
≤ 5mm.	L	45.5%	62.0%	44.0%	34.1%	30.5%	21.4%	39.9%
	R	43.2%	54.0%	48.0%	31.8%	34.0%	28.6%	40.3%
NO SPINE	L	9.1%	14.0%	0.0%	4.5%	2.8%	4.8%	5.8%
	R	6.8%	18.0%	0.0%	2.3%	2.8%	2.4%	5.4%
SAMPLE SIZE		44	50	50	44	49	42	279

TABLE 8.3 MASTOID FISSURE AND MEDIAL RECESS OCCURRENCE IN *H.ERECTUS* AND APES

Character states observed where possible in 7 APES and 20 casts of fossils attributed to *H.erectus*.

	GOR m	GOR f	Pan	ZHOU	SANG & SAM	NGAN	AFR
SAMPLE SIZE	2	1	4	5	5	6	4
MAST. FISSURE							
≥ 1.0mm.	2	1		3	3	6	
≥ .25mm.				1			
NO M.FISSURE							1
NO CREST LATERAL OF STYL.PROCESS			(4)				
NOT ASSESSABLE			4	1	2		3
DEPTH				1		1	
S=shallow				1	1		
D=deep	2	1					
MEDIAL RECESS							
>1.0mm.				4	3	2	3
≥.5mm.&<1.0mm.					1	1	
≥.1mm.&<.5mm.		1					
NO RECESS	2		4			1	
NOT ASSESSABLE				1	1	2	1
EP.SPINE SIZE							
> 5mm.							
≤ 5mm.					1?	2?	
NO SPINE	2	1	4	5	1	2?	3
NOT ASSESSABLE					3	2	1

Fig.8.2.1.2 Mastoid Fissure % Occurrence VS. Base Angle Gp.Mean



Cranial Base Flexion Angle Gp. Mean

Mastoid Fissure frequency decreases as cranial base flexion increases.

Australians have a very low frequency relative to cranial base flexion.

African representative, and present in the remaining 13 Asian cases. In all but one case (Zhoukoudian XI) the mastoid fissure is wider than 1mm. on at least one side, and it is particularly wide (up to 8mm.) in the 6 Ngandong representatives. Using the same categories as for modern humans, the depth of mastoid fissures in *H.erectus* casts varies from shallow to deep. However, the *H.erectus* sample includes fissures which are wider and deeper than any encountered in the modern human sample. Also, in the many cases where the *H.erectus* mastoid process is broken off, the original width and depth of the fissure is likely to have been even greater than that observed on the damaged material.

These observations are consistent with those of Brauer and Mbua, who also identified the mastoid fissure in one or more representatives of *A.africanus*, early *Homo*, one African *H.erectus* and archaic *H.sapiens* (Brauer & Mbua 1992:100).

Plotting % occurrence in modern humans of mastoid fissure $\geq$.25mm. (or $\geq$1mm.) against cranial base angle group mean, shows that mastoid fissure frequency tends to be greatest in groups with largest base angle means (Fig.8.2.1.2). This result supports Kennedy's suggestion of a link between cranial base flexion and mastoid fissure occurrence (Kennedy 1991:403), such that the more flexed the cranial base the less likelihood that a mastoid fissure occurs. Australians are an exception to this trend, having noticeably lower frequency of occurrence than expected for their comparatively flat base.

In the modern human sample it was further established that the mastoid fissure tends to occur more frequently on the right side than the left in every population sample except for Australians when the minimum fissure width is .25mm. This mastoid fissure asymmetry may be linked to the tendency in modern humans for the mastoid process, jugular fossa and sigmoid sulcus to be larger on the right side than the left. These 3 structures lie posterior to the tympanic plate; if larger on the right side, they may have the effect of rotating the petrosal crest downwards and anteriorly more on the right than the left, thus accounting for a greater frequency of mastoid fissures on the right side than the left.

SUMMARY

The mastoid fissure as defined here, occurs not only in apes (*Gorilla*) and *H.erectus* but also in approximately a third of modern humans. It is variable in expression in modern humans and between different population groups there is variation in occurrence, width and depth. % occurrence is particularly low in Poundbury crania; Gabon, Eskimo and Andamanese fissures tend to be widest; Andamanese fissures are predominantly shallow and Eskimo and Gabon fissures show greatest variation in depth. The mastoid fissure in *H.erectus* also varies in form and size, but generally reaches greater depth and width than in modern humans. Presence of a wide, deep mastoid fissure appears to be the primitive polarity.

Mastoid fissure presence must be discounted as a *H.erectus* autapomorph but may still be regarded as a useful descriptive trait. If so, then among modern humans, Poundbury, Chinese and Australians, the groups in which the fissure occurs least often, are least like *H.erectus* in this trait. On the basis of frequency of occurrence of the fissure relative to cranial base flexion, of all modern groups Australians are furthest from the *H.erectus* condition.

A negative connection between cranial base flexion and mastoid fissure presence is indicated for all modern groups except Australians; they have lower mastoid fissure incidence than expected for the group's mean base angle. It has not been determined if the same relationship between base flexion and mastoid fissure incidence is applicable outside modern humans, but if so the high incidence of well developed mastoid fissures in (Asian) *H.erectus* may be seen as a function of cranial base flatness.

In modern humans, a higher incidence of mastoid fissure on the right side may be linked to a tendency for a larger mastoid process, jugular fossa and sigmoid sulcus to occur on the right side. It is not known if a similar mastoid fissure asymmetry occurs in other hominids.

8.2.2.2 MEDIAL RECESS

The medial recess is defined by Rightmire as the "deep fissure between the (large) entoglenoid pyramid and the tympanic plate" (Rightmire 1990:189).

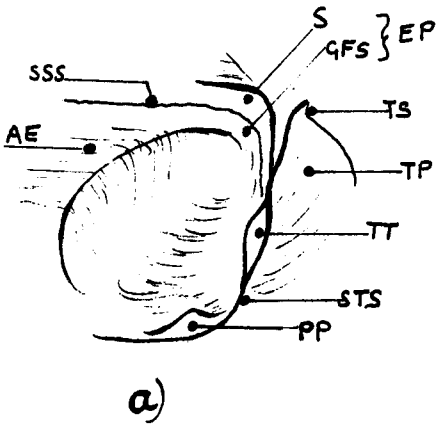
In the modern human sample considered in this study, great variation was found in the structure and conjunction of the entoglenoid pyramid (process) and the medial end of the tympanic plate (i.e. the medial and posterior walls of the glenoid fossa). The composition of the entoglenoid pyramid may be glenoid fossa squamous bone only or squamous and sphenoid with or without an inferior projection (spine) (Figs.8.2.2.1a & b). The spine can be pointed, rounded or irregular in shape and usually consists of sphenoid bone alone, but can also be composed partly of tegmen tympani and/or squamous from the glenoid fossa (Fig.8.2.2.1c). These 3 arrangements of tympanic and entoglenoid result in a meeting of the surfaces which ranges from a V-shaped recess of varying width, to a fine crevice, to no gap at all.

Quantifying the V-shaped recess is extremely difficult. For example, not only the depth but also the width of the gap depends on the "heights" (i.e. degree of inferior projection) of the two structures involved and their angles of inclination. At what threshold dimensions does a mere crack qualify as a recess? If the tympanic plate and the entoglenoid process are in contact, this is often a simple pressing together of the two surfaces, but occasionally partial fusion appears to have occurred. Not infrequently, the contact is complex, involving an interlocking of tympanic and sphenoid bone extensions (Fig.8.2.2.1d). In some cases, an extension from the sphenoid spine was observed to have grown superolaterally between the tympanic plate and tegmen tympani. Many of the variations in the conjunction of the entoglenoid process and the tympanic plate are pictured in Plate 8.2

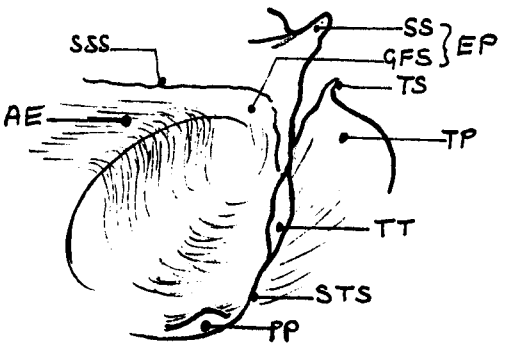
The absence and occurrence of the medial recess in each of 6 population samples is recorded in Table 8.2. If an interlocking of tympanic and entoglenoid process occurs this is recorded among the "no recess" cases. Percentage occurrence in 3 size ranges is noted. The recess is absent in Andamanese and Australians far more frequently than in other modern groups; less than 7% of Australian crania have recesses wider than 5mm. Chinese, Eskimo and Poundbury are the groups with

Fig.8.2.2.1 CONJUNCTION OF THE TYMPANIC PLATE AND ENTOGLENOID PROCESS

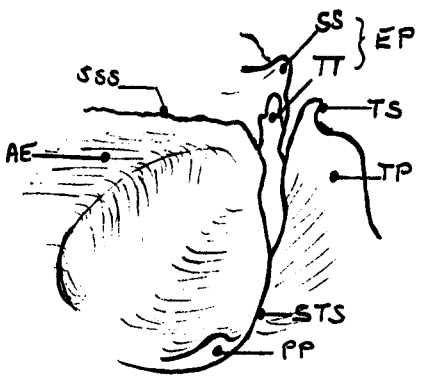
In diagrams a) to c) a V-shaped recess is indicated between the tympanic plate and the entoglenoid process. The size of the recess varies considerably, and in many cases the tympanic and entoglenoid process are in contact and sometimes fused.



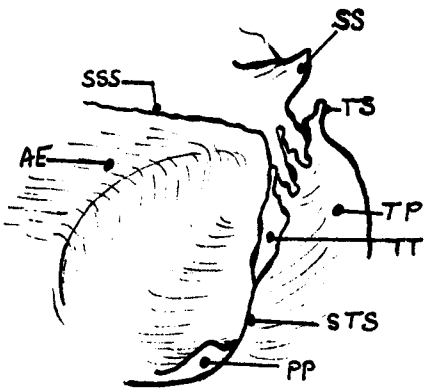
a)



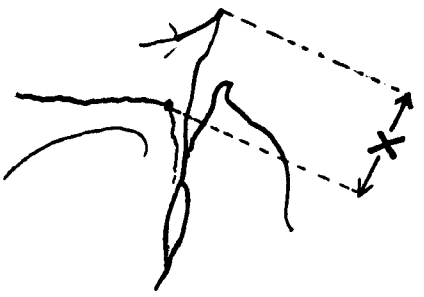
b)



c)



d)



e)

AE	Articular Eminence
GFS	Glenoid Fossa Squamous
EP	Ectoglenoid Process
PP	Postglenoid Process
S	Sphenoid Bone
SS	Sphenoid Spine
SSS	Squamosphenoid Suture
STS	Squamotympanic Suture
TP	Tympanic Plate
TS	Tympanic Supratubalis
TT	Tegmen Tympani
X	Sphenoid Spine Length

a) Entoglenoid process consists of squamous and sphenoid, or squamous alone, but no sphenoid spine is present.
b) Entoglenoid process consists of squamous and sphenoid, and includes a sphenoid spine which is pointed, rounded or blunt.
c) Tegmen tympani extends into the sphenoid and is part of the spine.
d) Extensions of the tympanic plate (and sometimes tegmen tympani) interlock with the sphenoid bone.
e) X is the length of the sphenoid spine.

Plate 8.2 MEDIAL RECESS VARIATION IN MODERN HUMANS

Variation associated with the Medial Recess is seen in the presence or absence of the recess and sphenoid spine, their size and shape, the orientation of the sphenoid spine and the composition of the entoglenoid process. Some examples of medial recess variation are depicted in plates a-p. The LEFT temporal is depicted in plates a,d,g,m,n,o and p; the RIGHT temporal region is depicted in the other plates.

G = glenoid fossa; H = foramen of Huschke; MP = mastoid process; R = medial recess; S = supratubalis; Sp = sphenoid bone, sphenoid spine; T = tympanic plate; TT = tegmen tympani;

a) Narrow, deep medial recess, no sphenoid spine, entoglenoid process composed of glenoid squamous only ['64:6/7/69A, Gabon].

b) No recess because the parts are pressed tightly together, no sphenoid spine, entoglenoid process composed of glenoid squamous only [3349, New Britain].

c) No recess because the parts are pressed tightly together, glenoid fossa extends to project with sphenoid spine [7.699, Chinese].

d) Small medial recess ['90:5/14/1, Andamanese].

e),f),g) and h) Medial recess and pointed sphenoid spine present; recess large in h), spine varies from robust (e) to fine (g). [PC794, Poundbury; 21.0.5, Chinese; 7.6121, Chinese; '64:6/7/66, Gabon, respectively].

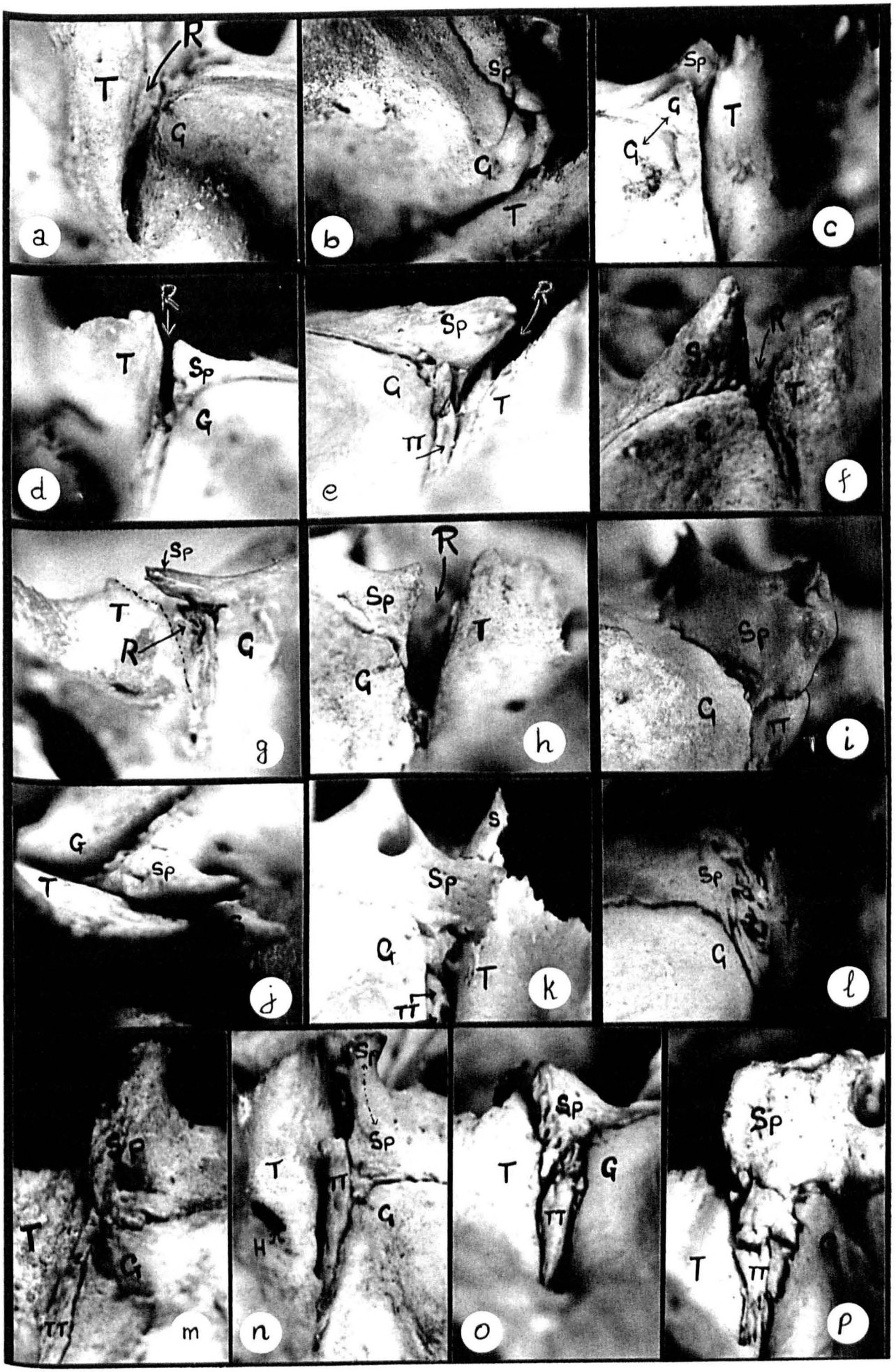
i) and m) No medial recess because tympanic plate, glenoid squamous, tegmen tympani and large, robust sphenoid protuberance are fused [i) 3345, New Britain; m) BD1172, Eskimo].

j) and k) No medial recess because the sphenoid projection overlaps and touches the tympanic plate and supratubalis. The sphenoid protuberance is robust and pointed in j)[30/984, Australian], and wide and blunt in k) [10/840, Eskimo].

l) No medial recess because of a complex interlocking of extensions fron the sphenoid and tympanic regions [3342, New Britain].

n) No medial recess because glenoid squamous, tympanic plate, large sphenoid spine and large tegmen tympani are in close contact [8.0331, Andamanese].

o) and p) No medial recess because of complex fusion and interlocking of prominent tegmen tympani and extremely large sphenoid protuberance with tympanic plate and glenoid squamous. Sphenoid bone has extended into the space between tympanic and glenoid fossa [10/846 & FC810, Eskimos].


a
R
T
G
b
Sp
G
T
c
Sp
G
G
T
d
R
T
Sp
G
e
Sp
R
G
T
TT
f
S
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h
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i
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Sp
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TT

highest recess frequency, but in Poundbury crania most gaps are no more than crevices narrower than .5mm. Few crania in any group have recesses wider than 1.0mm.; Chinese have the highest frequency (11.4%) and overall only 7.3% of the total modern human sample have medial recess wider than 1.0mm.

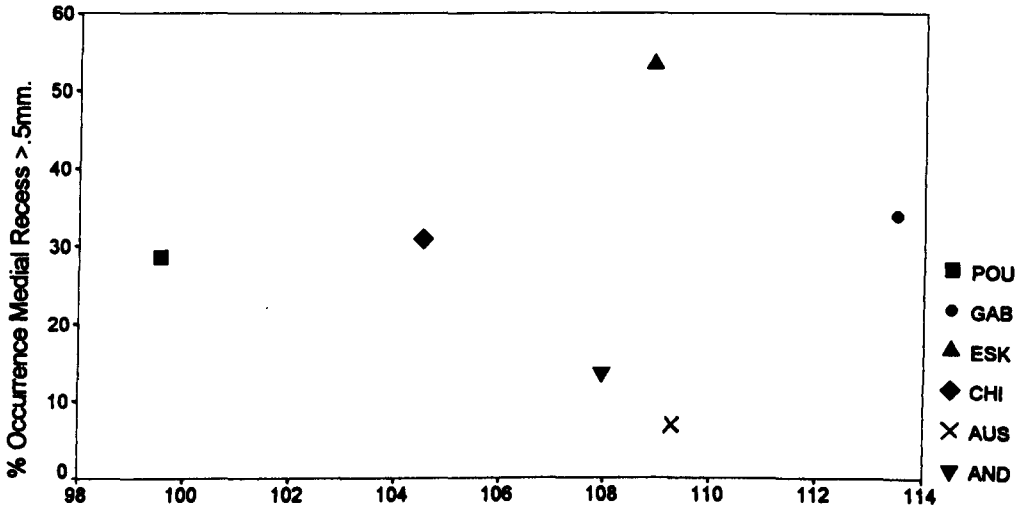
A sphenoid spine is nearly always a part of the modern human entoglenoid process. Only 5.6% of the modern crania have no spine and in more than half the sample a spine longer than 5mm. was present (Fig.8.2.2.1e & Table 8.2). Sphenoid size but not occurrence is related to overall cranial size (Fig.8.2.2.5 & 6). Longer spines are associated with groups which have large cranial size group means. Sphenoid spines occur least frequently in Gabon crania, and are absolutely and relatively shorter than in any other modern human group . It is present in all Australian crania.

Apart from a fine crevice in the female gorilla, no medial recess was observed in the ape sample (Table 8.3). The very prominent entoglenoid pyramid/process in *Gorilla* and *Pan* is an extremely robust, inferiorly projecting structure consisting mostly or wholly of thick temporal squama. It closely contacts the tympanic plate surface and/or the robust supratubalis, leaving no recess between. The sphenoid is insignificant at this junction and no sphenoid spine is associated with the entoglenoid process.

In most of the Asian *H.erectus* material the appropriate region is adequately preserved on only one side. In 3 cases, a sizeable recess exists on one side but is absent on the other. For each case, the feature was recorded present if a recess was observed on one or both sides. A medial recess was found on all but one of the specimens able to be assessed, and of those 14, 12 were wider than 1mm. (Table 8.3). The 2 medial recesses in the African fossil ER3733 are the largest observed. Rightmire found some Ngandong crania depart from the *H.erectus* pattern, the recess being narrow or absent. Brauer and Mbua (1992:101-105) noted the medial recess is present in some australopithecines, early *Homo* and archaic *H.sapiens*.

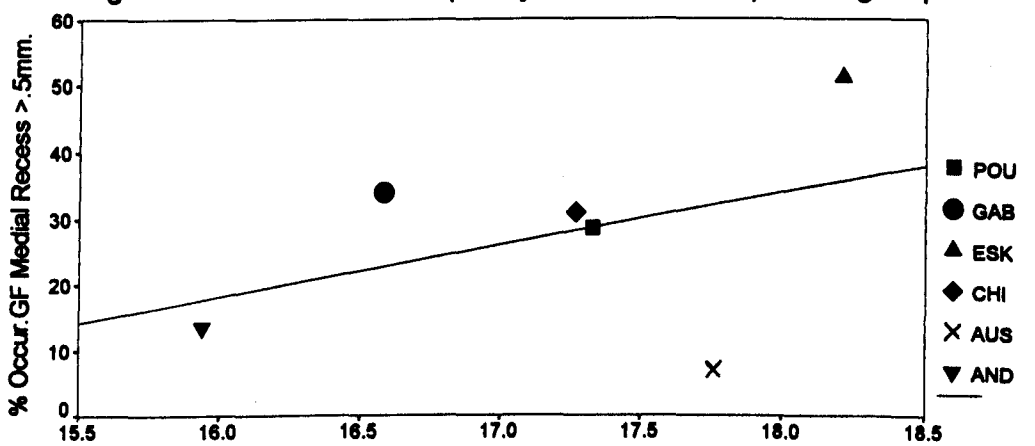
There is no trace of a sphenoid spine associated with the entoglenoid process in African and Sinanthropus *H.erectus* specimens. A small sphenoid spine is present in Sangiran 17 but not as part of the entoglenoid process. The situation is less clear in Ngandong cranial casts; a small sphenoid spine

Fig 8.2.2.2 Medial Recess % Occurrence VS. Base Angle Gp.Mean



Cranial Base Flexion Angle Gp.Mean

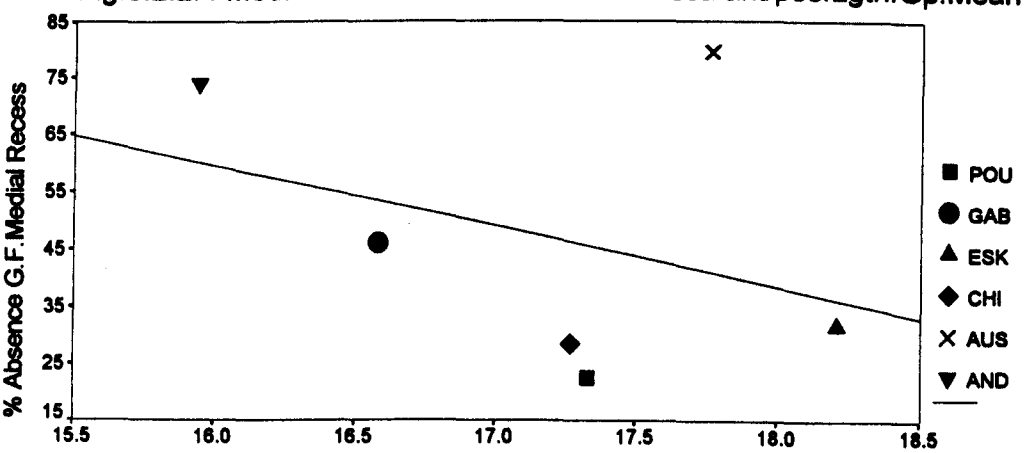
Fig.8.2.2.3 Med.RecessFrequency vs.G.Fossa ant/pos.LengthGp.Mean



Glenoid Fossa ant/post Length--Group Mean

Medial recesses occur most frequently in modern groups with long glenoid fossae, and are most rare, relatively and absolutely, in Australians.

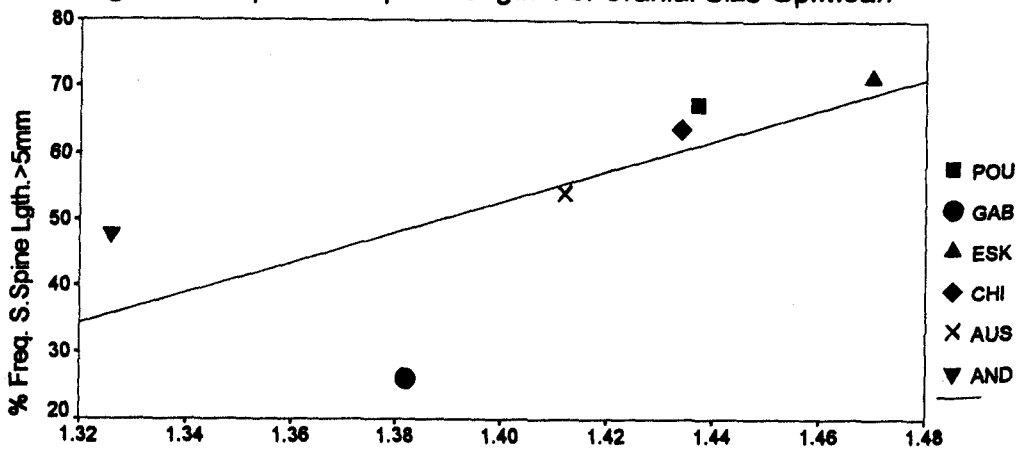
Fig.8.2.2.4 Med. Recess % Absence vs.G.Fossa ant/pos.Lgth.Gp.Mean



Glenoid Fossa ant/post Length-- Gp.Mean

The medial recess is absent more frequently in modern human groups with short (ant/post) glenoid fossae. % absence in Australians is very high.

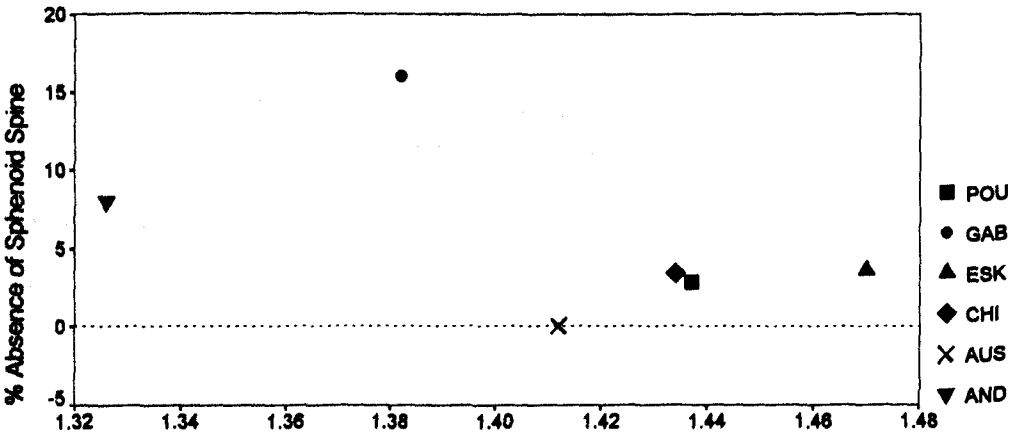
Fig.8.2.2.5 Sphenoid Spine Length VS. Cranial Size Gp.Mean



Cranial Size Group Mean

Sphenoid length tends to increase with cranial size. Gabon tend to have short sphenoid spines, absolutely and relatively.

Fig.8.2.2.6 Sphenoid Spine Absence VS. Cranial Size Gp.Mean



Cranial Size Group Mean

Groups with small cranial size tend to have low sphenoid spine frequency

Absence is highest in Gabon, lowest in Australians.

appears to exist in Ngandong 7 and 12. However, Rightmire claims that sphenoid bone may contribute to the entoglenoid process in *H.erectus* but not as a spine (Rightmire 1990:177).

Kennedy (1991:403) suggested that, as for mastoid fissure, medial recess occurrence may be related to cranial base flexion. No such link is evident, at least not within the modern human sample, when medial recess frequency is plotted against cranial base flexion (Fig.8.2.2.2).

Weidenreich thought that the existence of the medial recess may be associated with the anterior-posterior compression of the glenoid fossa (Weidenreich 1943:47). When (i) % occurrence of recess >.5mm. and (ii) % absence of the recess in each of the 6 modern human groups is plotted against glenoid fossa ant/post.length group mean, some association is indicated (Figs.8.2.2.3 & 4). The results suggest that with the exception of Australians, occurrence and size of the medial recess is positively associated with glenoid fossa ant/post. length. Compared to other modern groups, the Australian frequency of medial recess presence is particularly low when considered relative to glenoid fossa ant/post.length.

SUMMARY

The conjunction of the medial and posterior walls of the glenoid fossa is very variably expressed in modern humans. A narrow medial recess is present in half the modern human crania examined; in a quarter of the sample the recess is wider than .5mm., but rarely is it wider than 1mm. The recess is far less common in Australians and Andamanese than in other modern groups; e.g.less than 7% of Australian crania have a recess wider than .5mm. The longest sphenoid spines tend to be associated with largest crania. The sphenoid spine is least frequent and shorter in Gabon than in other groups, and most frequently present in Australian crania (100%).

In *Gorilla* and *Pan* crania a very large, thick entoglenoid pyramid lies in close contact with the tympanic; the medial recess is absent and a sphenoid spine is not part of the entoglenoid process. From observation of the casts and descriptions in the literature, the presence of a medial recess wider than 1mm. and absence of a sphenoid spine as part of the entoglenoid process is characteristic of *H.erectus*. But in a few cases, a narrower recess and/or possible sphenoid

spine were observed.

Though a prominent feature of both African and Asian *H.erectus* and absent in African apes, since the medial recess also occurs in hominids which came before and after *H.erectus*, including modern humans, it cannot be regarded as a feature unique to *H.erectus* in general, let alone Asian *H.erectus* in particular. Of the modern human groups, Australians and Andamanese differ most from the *H.erectus* expression of this feature.

Within the modern human sample, no evidence was found of a link between medial recess occurrence and cranial base flexion, but there does appear to be a positive link between recess frequency and glenoid fossa ant/post.length$_{\wedge}$ (as proposed by Weidenreich (1943:47)). Perhaps the elimination or reduction in size of the medial recess seen in modern humans is related to ant/post. compression of the cranial base from H.erectus to modern humans.

8.2.2.3 CURVATURE OF THE MEDIAL REGION OF THE TYMPANIC PLATE

Weidenreich (1943:202,203,54) said that for Asian *H.erectus* "the part of the tympanic plate which forms the posterior wall of the mandibular fossa is either plane or more or less convex, where it is concave in modern man", that the *H.erectus* condition resembles that prevailing in apes and that the difference in shape is at least partly attributable to the difference in thickness of the tympanic. Larnach and Macintosh regarded a convex tympanic as a characteristic trait of Ngandong (Larnach & Macintosh 1974:97).

In the modern human sample, the shape of the medial section of the tympanic plate which forms the posterior wall of the glenoid fossa was categorized by inspection as concave, straight or convex. The results are recorded in Table 8.4. Nearly 3/4 of the tympanic plates in the total modern human sample are concave, but the condition varies considerably between groups. Straight and convex shape is rare in Chinese, Poundbury and Eskimo groups, in which the 93.2-100% of the tympanic plates are concave. Andamanese are exceptional in having an extremely high frequency of convex or straight condition (81.8% [L], 86.3% [R]); an example of this is pictured in Plate 8.3. Australian and Gabon crania are at neither extreme, but the concave condition in both groups is

Plate 8.3

TYMPANIC CURVATURE

A concave medial region in the tympanic plate is the usual condition in all modern human groups except Andamanese; 59.8% of Andamanese tympanic plates are convex.

ANDAMANESE (1905.11/25/2)

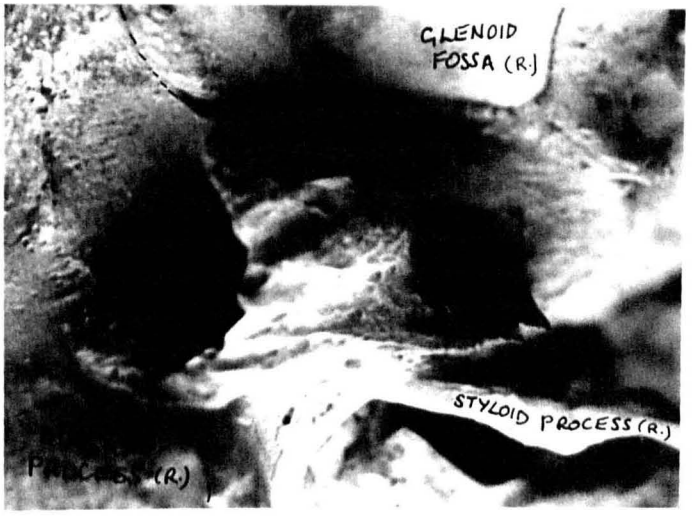
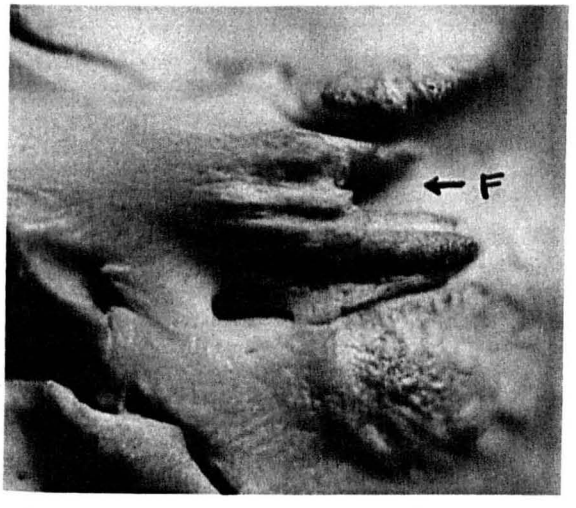


Plate 8.5 TYMPANIC PLATE DEHISCENCE

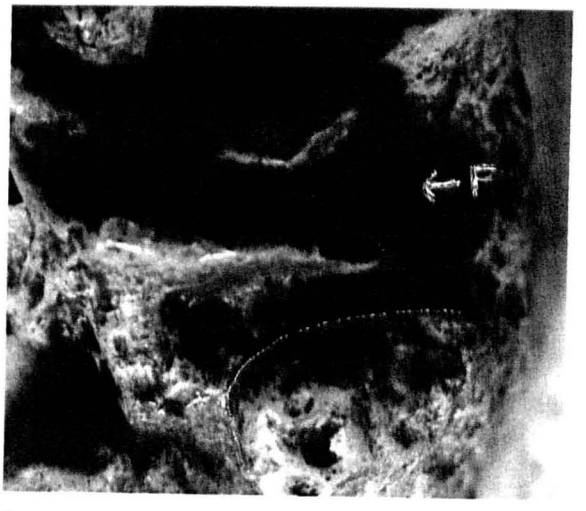
IN APES, *H.ERECTUS* AND MODERN HUMANS

F = dehiscence in tympanic plate floor

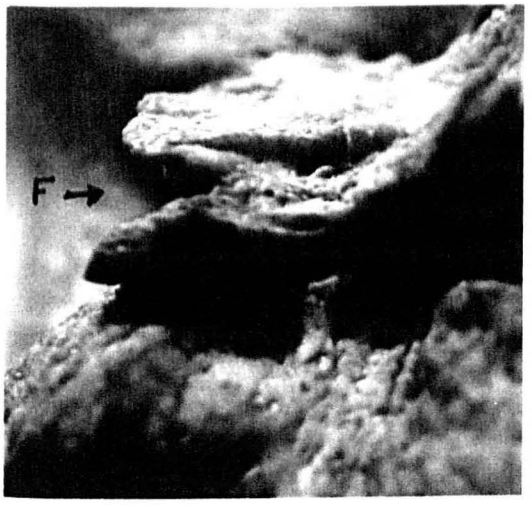
a) African Ape(*PAN*),1195,Left



b)*SINANTHROPUS* IIIE,Left



c) ESKIMO AM1.0.7,Right



d)ANDAMANESE '90.5/14/1,Right

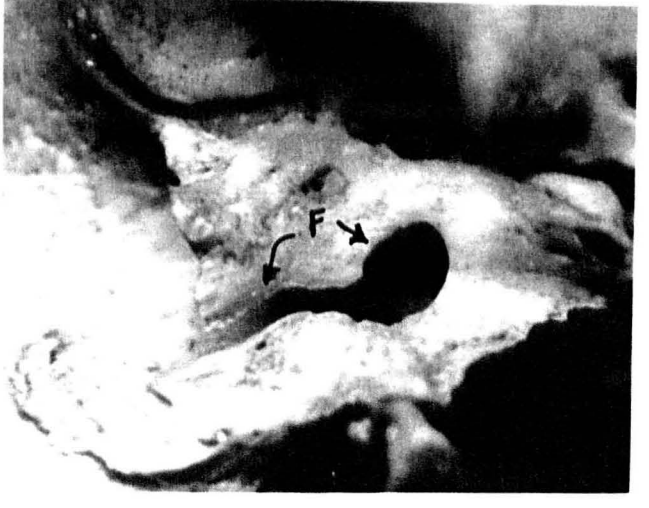


TABLE 8.4
TYMPANIC CURVATURE, FORAMEN OF HUSCHKE PRESENCE, SUPRATUBALIS LENGTH AND TEGMEN TYMPANI WIDTH IN MODERN HUMANS

	AND	GAB	AUS	CHI	POU	ESK	TOTAL
TYM.CURVATURE							
Concave L	18.2%	79.2%	72.5%	93.2%	98.0%	97.6%	76.6%
R	13.6%	85.4%	72.5%	95.5%	95.9%	100 %	77.3%
Straight L	25.0%	12.5%	15.7%	2.3%	2.0%	2.4%	10.1%
R	13.6%	8.3%	19.6%	0.0%	4.1%	0.0%	7.9%
Convex L	56.8%	8.3%	11.8%	4.5%	0.0%	0.0%	13.3%
R	72.7%	6.3%	7.8%	4.5%	0.0%	0.0%	14.7%
SAMPLE SIZE	44	48	51	44	49	42	280
F.OF HUSCHKE							
Present L	30.0%	26.0%	8.0%	25.0%	10.2%	26.2%	20.4%
R	31.0%	32.0%	6.0%	20.5%	12.2%	31.0%	21.7%
Absent L	70.0%	74.0%	92.0%	75.0%	89.8%	73.8%	79.6%
R	69.0%	68.0%	94.0%	79.5%	87.8%	69.0%	78.3%
SAMPLE SIZE	42	50	50	44	49	42	277
SUPRATUBALIS							
Present≥5mm. L	0.0%	2.0%	8.2%	2.3%	0.0%	4.8%	2.9%
R	0.0%	2.0%	8.2%	2.3%	0.0%	4.8%	2.9%
Absent L	42.9%	52.0%	32.7%	86.4%	65.3%	33.0%	52.2%
R	38.1%	56.0%	32.7%	79.5%	65.3%	40.5%	52.2%
SAMPLE SIZE	42	50	49	44	49	42	276
TEGMENTYMPANI							
> 1mm. L	77.3%	10.0%	49.0%	43.2%	40.8%	61.9%	46.0%
R	75.0%	12.0%	49.0%	50.0%	40.8%	61.9%	47.1%
Absent L	0.0%	50.0%	10.2%	9.1%	14.3%	0.0%	14.7%1
R	0.0%	36.0%	16.3%	11.4%	12.2%	7.1%	4.4%
SAMPLE SIZE	44	50	49	44	49	42	278

TABLE 8.5.
TYMPANIC CURVATURE, FORAMEN OF HUSCHKE PRESENCE, SUPRATUBALIS LENGTH AND TEGMEN TYMPANI WIDTH: Observed where possible in 7 APES and 20 casts of fossils attributed to *H.erectus*.

	GOR m 2	GOR f 1	PAN 4	ZHOU 5	SANG & SAM 5	NGAN 6	AFR 4
TYM.CURVATURE							
Concave					1		
Straight			2				
Convex	2	1	2	5	2	6	1
NOT ASSESSABLE					2		3
SUPRATUBALIS							
Present≥5mm.	2	1	4			1	
Absent					1	1	1
NOT ASSESSABLE				5	4	4	3
F.OF HUSCHKE							
Present				1?			
Absent	2	1	4	4	5	6	3
NOT ASSESSABLE							1
TEGMEN TYMPANI							
> 1 mm.							
Absent	2	1	4				
NOT ASSESSABLE				5	5	6	4

more likely (72.5%-85.4%).

No case of concave tympanic was found in the ape sample. (Table 8.5). 2 *Pan* have straight tympanic sections, the rest are convex. In 4 of the 19 *H.erectus* casts, the tympanic plates are missing, damaged or indeterminate in shape. Sangiran 4 has a concave tympanic shape but the remaining 14 (including all Ngandong) have convex tympanic plates.

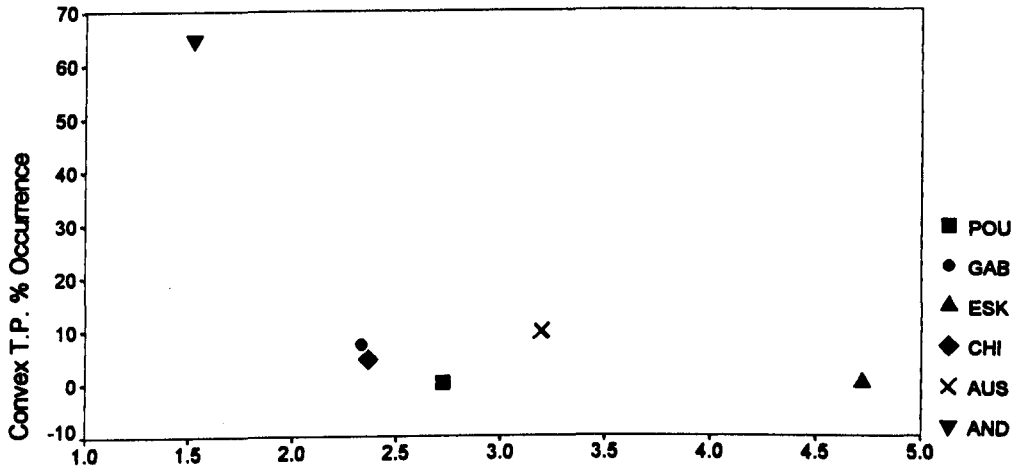
The % occurrence in modern humans of the concave and convex conditions was plotted in turn against group means of (i) tympanic rim thickness, (ii) tympanic plate height and (ii) cranial size (Figs.8.2.3.1-6). No relationship between tympanic curvature and tympanic rim thickness is indicated (Figs.8.2.3.1 & 2). Andamanese, the group with by far the highest frequency of the convex condition, also has the lowest group mean for tympanic rim thickness. Granted Weidenreich was referring to medial, not lateral thickness when he suggested a link between convexity and tympanic thickness, but since Andamanese have the highest frequency of Foramen of Huschke occurrence it might be expected that the group is also associated with a particularly thin medial tympanic region.

A weak link is indicated between tympanic curvature and (i) cranial size (ii) tympanic height such that the likelihood of concavity increases as cranial size group mean increase and tympanic height group mean (Figs.8.2.3.3-6).

SUMMARY

The convex and straight condition does occur in modern humans, though in low frequency in most populations. Although Andamanese tend to have the thinnest tympanic plates, laterally and medially, they also show by far the highest frequency of convexity in the medial tympanic region. There is no support, at least within the modern human sample, for attributing medial tympanic convexity to medial tympanic thickness. The results do support the view that the primitive polarity for this feature is a convex or straight medial tympanic region.

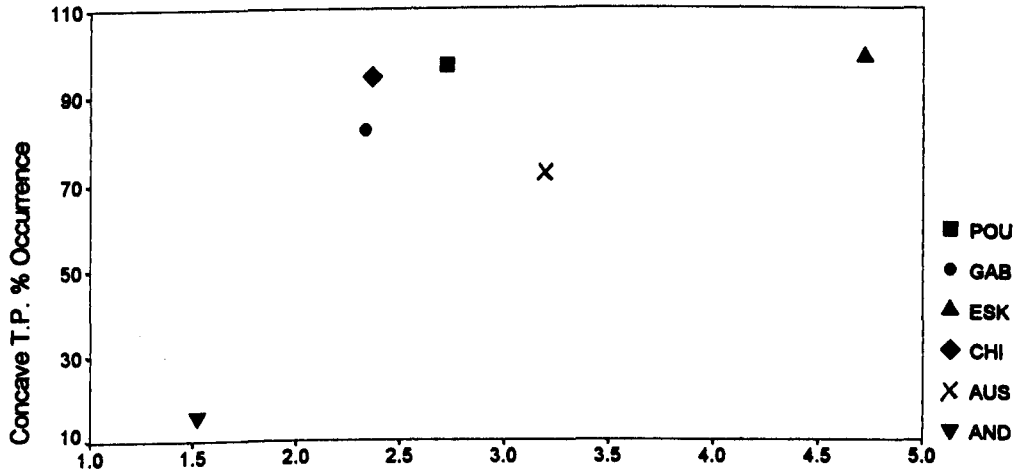
Fig.8.2.3.1 %Convex Curvature vs.TympanicThickness Gp.Mean



Tympanic Plate Thickness Gp. Mean

Andamanese have extremely high frequency of medial tympanic convexity.

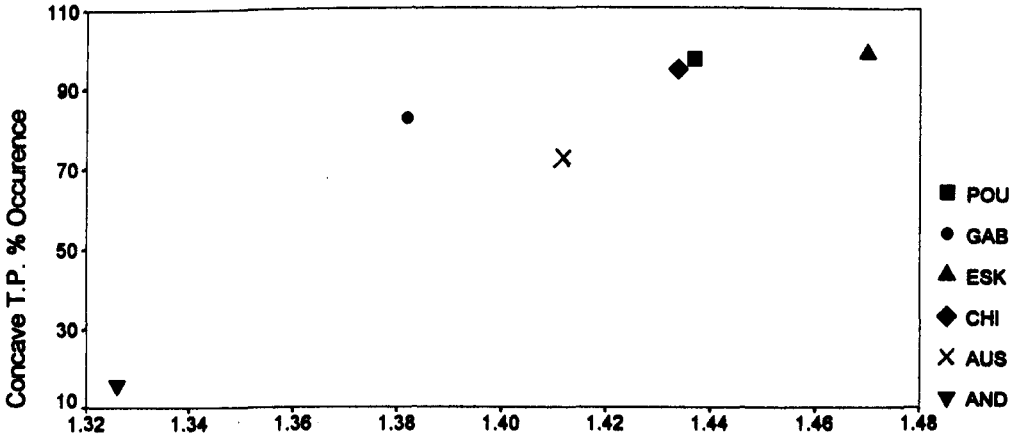
Fig.8.2.3.2 % Concave Curvature vs.TympanicThicknessGp.Mean



Tympanic Plate Rim Thickness Gp. Mean

Andamanese have exceptionally low frequency of medial tympanic concavity

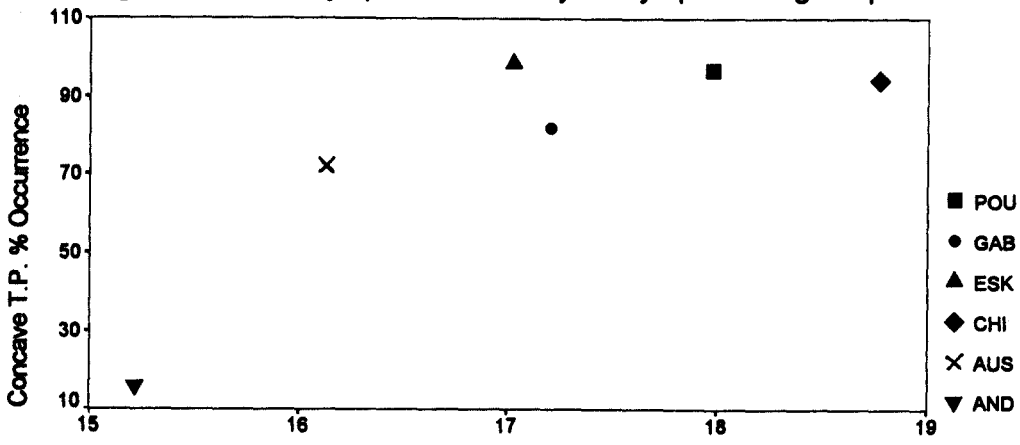
Fig.8.2.3.3 Medial Tympanic Concavity Vs. Cranial Size Gp.Mean



Cranial Size---Group Mean

There is some tendency for medial tympanic concavity to be most frequent in groups with largest crania.

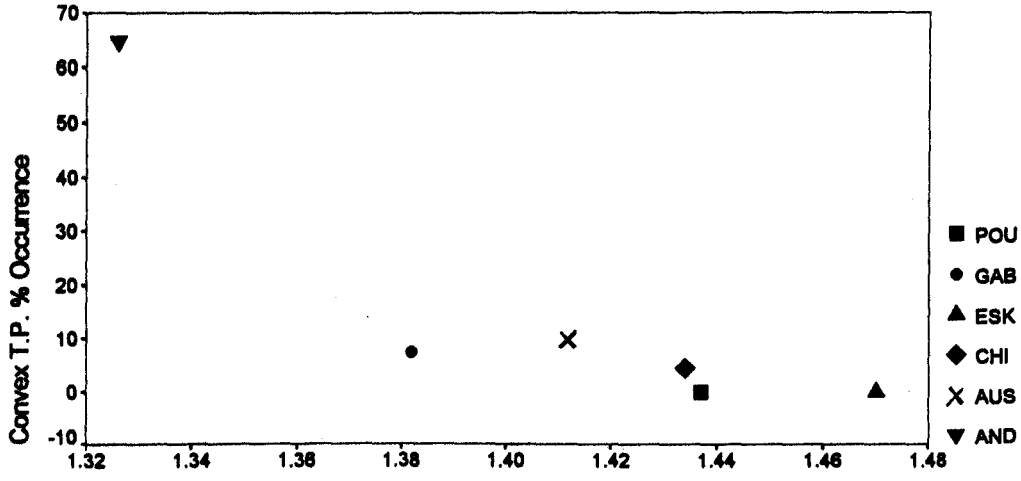
Fig.8.2.3.4 Med.Tympanic Concavity vs.TympanicHeight Gp.Mean



Tympanic Plate Height ---- Gp. Mean

The frequency of medial tympanic concavity tends to increase as tympanic plate height increases.

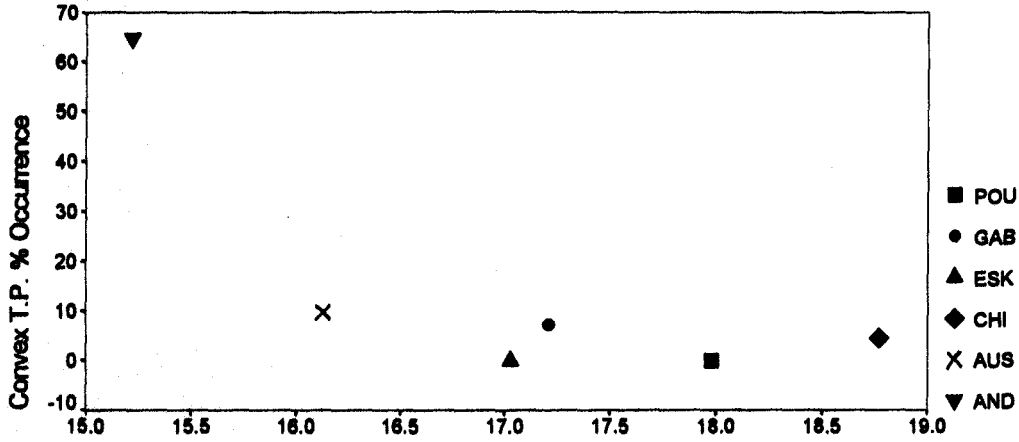
Fig.8.2.3.5 Medial Tympanic Convexity Vs. Cranial Size Gp.Mean



Cranial Size (cub.rt.LxBxH)

A convex medial tympanic is uncommon in modern humans except Andamanese.

Fig.8.2.3.6 Med.Tympanic Convexity vs.TympanicHeight Gp.Mean



Tympanic Plate Height

Medial tympanic convexity is common only in Andamanese and may be weakly associated with low tympanic height.

8.2.2.4 SUPRATUBALIS PROCESS

The supratubalis process was originally defined by Weidenreich (1943:61,204). He described it in *H.erectus* as a swelling or "small, round tuber-like elevation" marking the medial anterior end of the tympanic plate, in modern humans as a fine spine-like projection representing the termination of the petrous crest, and in anthropoids as a large sharp-pointed protuberance. Rightmire describes the process "supratubarius" in *H.erectus* as a blunt tubercle, the medial termination of the petrosal crest (Rightmire 1991:177,189). A more consistent and explicit definition of the feature is necessary for a meaningful comparison of expression within the modern human sample and between apes, modern humans and *H.erectus*.

From an overview of the range of variation in the shape of the medial end of the tympanic plate in apes and modern humans, 4 conditions exist:

(a) A straight projection or process, usually pointed, extends from the anterior side of the medial end of the tympanic (Fig.8.2.4.1 a).

(b) The same structure as in a), except that the process appears sometimes bent back on itself (Fig.8.2.4.1 b).

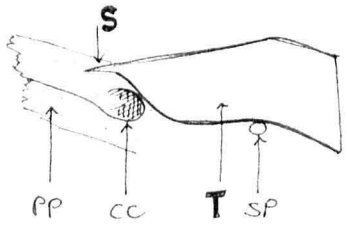
(c) Medially, the tympanic has a chisel-shaped ending; no process projects from the anterior side. The blunt tympanic ending may lie flat against the petrous pyramid or show varying degrees of prominence. No satisfactory method was found to quantify variation in its degree of relief or robustness (Fig.8.2.4.1 c).

(d) The medial end of the tympanic plate has neither an anterior projection nor a distinct ending. Rather it merges with the petrous pyramid surface in the carotid canal region (Fig.8.2.4.1 d).

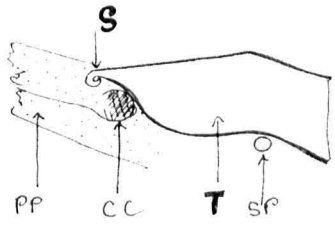
In many modern human cases it was found impossible to distinguish between conditions (c) and (d), so the specimens have been categorized by the simpler, less ambiguous criterion of whether a medial anterior process is present (conditions (a) and (b)), or absent (conditions (c) and (d)). The lengths of all processes were measured. Tables 8.4 & 5 record the findings as % absence of the supratubalis process, and as % occurrence of processes >5mm. in length.

Fig.8.2.4.1 MEDIAL END OF THE TYMPANIC PLATE

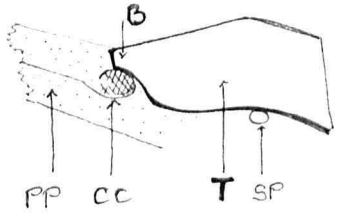
a) STRAIGHT POINTED SUPRATUBALIS PROCESS



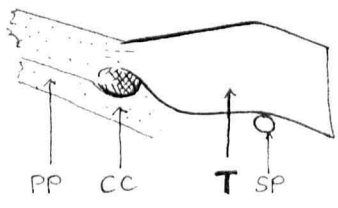
b) BENT SUPRATUBALIS PROCESS



c) BLUNT MEDIAL TYMPANIC END NO SUPRATUBALIS PROCESS



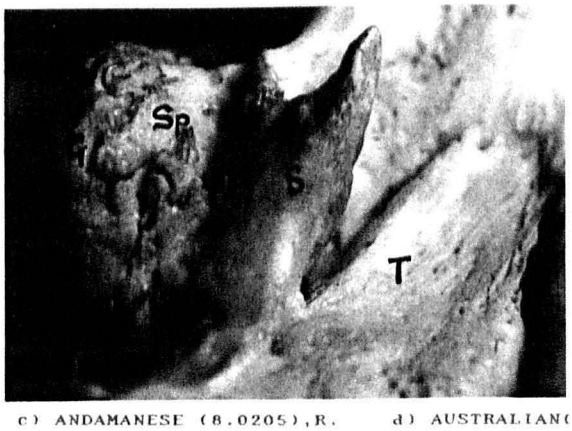
D) FUSED MEDIAL TYMPANIC END NO SUPRATUBALIS PROCESS



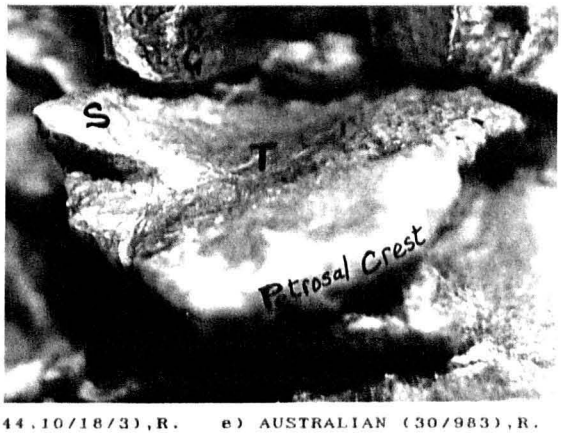
S = SUPRATUBALIS PROCESS
B = BLUNT TYMPANIC MEDIAL END
T = TYMPANIC PLATE
G = GLENOID FOSSA
CC = CAROTID CANAL
PP = PETROUS PYRAMID
SP = STYLOID PROCESS

Plate 8.4
SUPRATUBALIS IN APES, *H.ERECTUS* AND MODERN HUMANS.

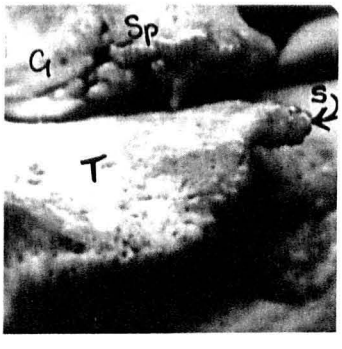
a) *GORILLA* ♂ (1192), Right



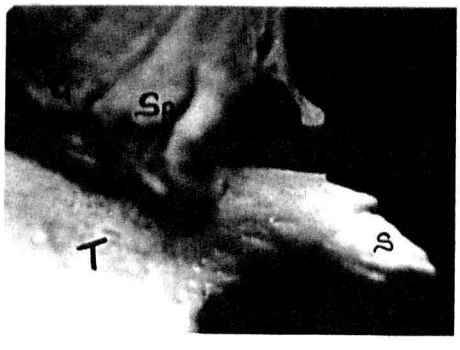
b) NGANDONG 7, Left



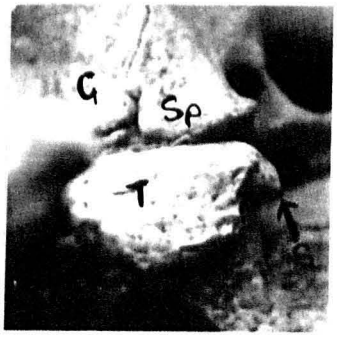
c) ANDAMANESE (8.0205), R.



d) AUSTRALIAN('44.10/18/3), R.



e) AUSTRALIAN (30/983), R.



In apes, the supratubalis process was found to be always present, pointed, very prominent and robust, extremely so in the 2 male *Gorilla*. The equivalent projection in modern humans appears to be an identical structure, but greatly reduced in size. The supratubalis process was found to be completely absent in approximately half (52.2%) the total modern human sample and frequency of occurrence varies considerably between different populations. It is present most frequently in Australian and Eskimo crania, and absent particularly frequently in Chinese crania. When present, the process is rarely as long as 5mm. in modern humans, only 2.9% of the total sample, and is often bent over. The longest processes tend to occur in Australian crania, but still only 8.2% are 5mm. or more in length.

It is not possible in this study to satisfactorily compare the condition in apes and modern humans with that in *H.erectus* since the supratubalis is inadequately described in the literature with regard to size and shape in the original *H.erectus* material, and the condition on most casts is not clear enough to assess. Ngandong 7 cast is the only case where a definite projection is identifiable, and it is similar to one of the larger examples in modern humans. Even in the original *Sinanthropus* material, Weidenreich identified the supratubalis process in only one cranium, Skull IIIE, presuming it had existed but had been broken off in the other *Sinanthropus* crania. Rightmire considered the supratubalis process a characteristic feature of all African and Asian *H.erectus*, but his description of it as a blunt termination of the petrosal crest would cover most cases found in modern humans where an actual anterior projection is not present.

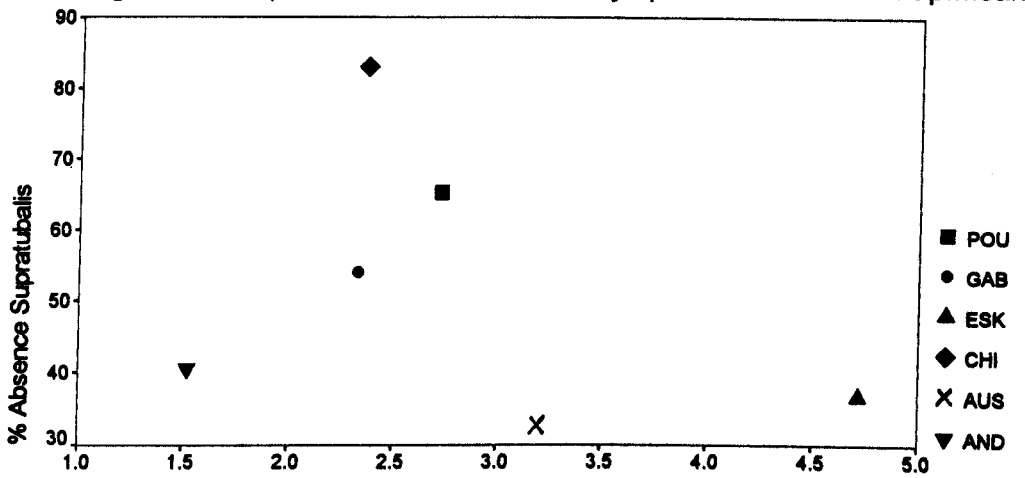
Examples of the presence of a supratubalis process in apes, *H.erectus* and modern humans is pictured in Plate 8.4.

No evidence was found of the occurrence or length of supratubalis process being linked to tympanic rim thickness or cranial size (Figs.8.2.4.2 & 3).

SUMMARY

A supratubalis process is a common feature in modern humans, though it is greatly reduced in robusticity and length (rarely as long as 5mm.) compared to the ape condition. The process is more likely to occur in some modern population

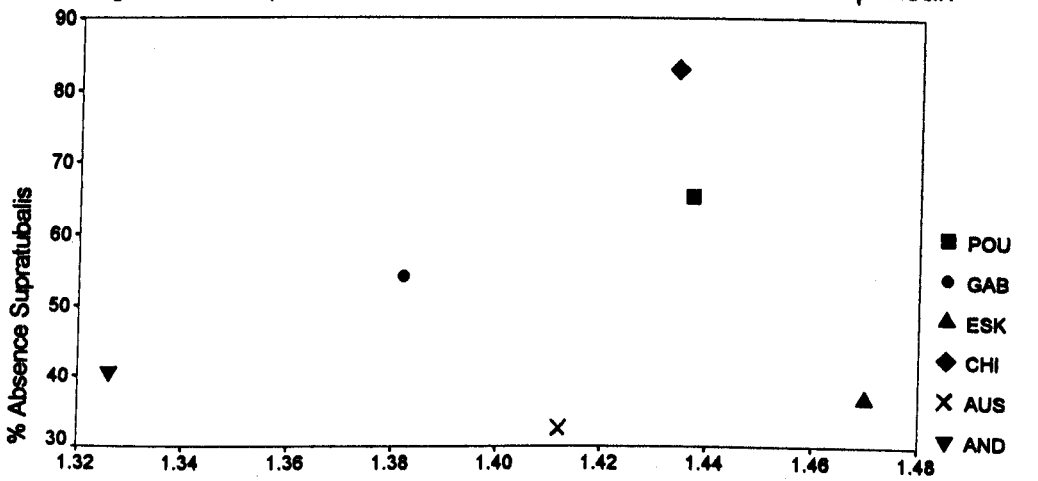
Fig.8.2.4.2 Supratubalis %Absence vs.TympanicRimThicknessGp.Mean



Tympanic Rim Thickness Group Mean

No link is evident between Supratubalus occurrence & tympanic thickness.

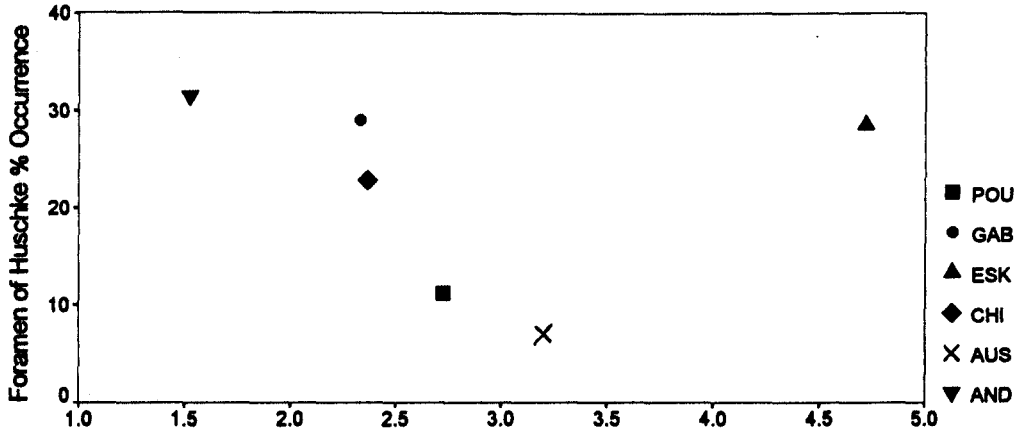
Fig.8.2.4.3 Supratubatubalis % Absence vs. Cranial Size Gp.Mean



Cranial Size (cub.rt.LxBxH)

No evident link exists between supratubalis occurrence and cranial size.

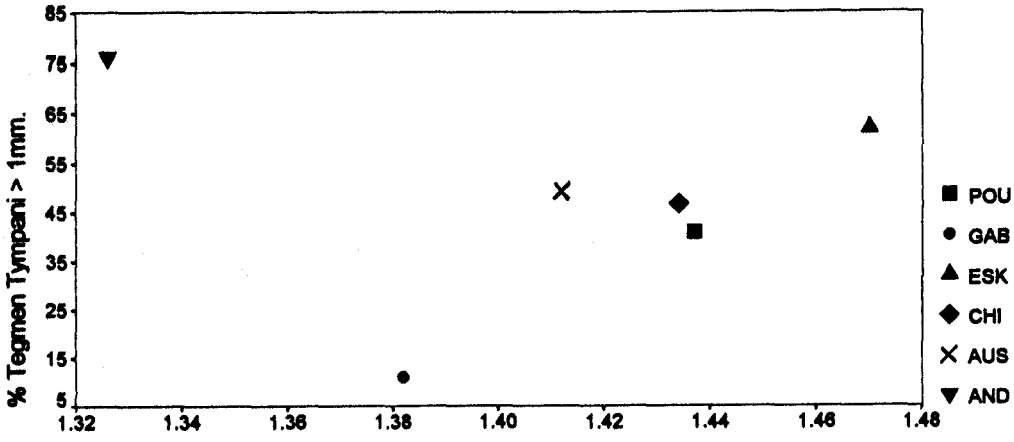
Fig.8.2.5.1 Foramen of Huschke Frequency vs. Tympanic Rim Thickness



Tympanic Plate Lateral Rim Thickness

The thicker a group's mean tympanic rim the lower its foramen of Huschke frequency. Eskimos have a v. high frequency for their mean rim thickness

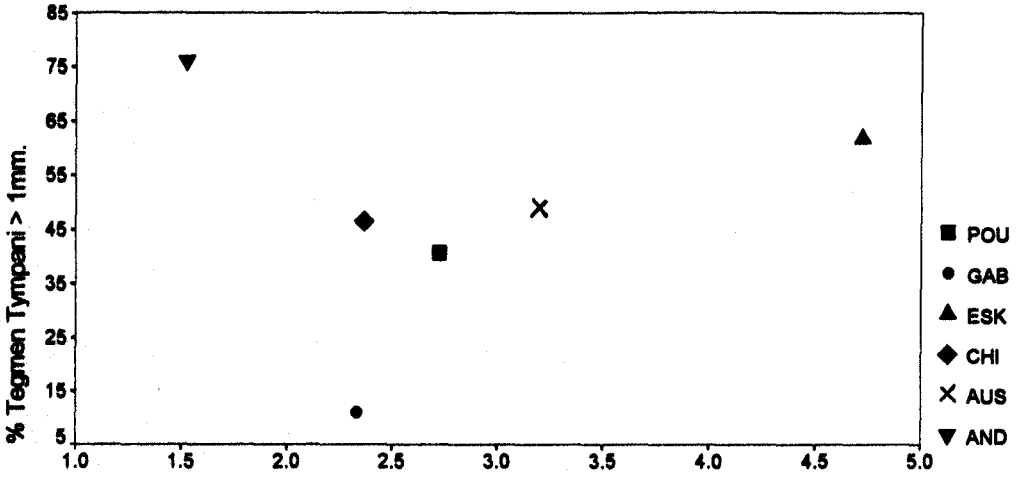
Fig.8.2.6.1 % Tegmen Tympani >1mm. vs. Cranial Size Gp.Mean



Cranial Size (cub.rt.LxBxH)

The incidence of tegmen tympani >1mm. increases as a group's cranial size increases. Andamanese are exceptional with a very high incidence.

Fig.8.2.6.2 % TegmenTympani>1mm.vs.TympanicThickness Gp.Mean



Tympanic Rim Thickness Group Mean

Frequency of Tegmen tympani >1mm is not linked to tympanic rim thickness

groups than others. It is most frequently present in Australian and Eskimo crania, and absent most frequently in Chinese crania. Australian crania tend to have the longest processes, but rarely do they exceed 5mm. in length. A reliable comparison cannot be made with the condition expressed in *H.erectus*, but the results suggest that a long, straight, pointed and robust anterior medial tympanic end as seen in *Gorilla* is the primitive condition. No link with cranial size or tympanic thickness was found.

8.2.2.5 FORAMEN OF HUSCHKE

The foramen of Hushcke (incomplete development of the medial floor of the tympanic plate) was found to be present in a fifth (21.1%) of tympanic plates in the total modern human sample (Table 8.4). The occurrence is considerably less in Australian and Poundbury crania than in other groups.

While it is true that in modern humans the tympanic plate is thinner medially than laterally, some correspondence between lateral and medial thickness might be expected such that a tympanic plate with a comparatively thick rim would also have a comparatively thick medial region, and consequently less likelihood of the presence of a foramen of Huschke. For 5 of the 6 modern human groups, the frequency of occurrence of foramen of Huschke was found to decrease as the group mean tympanic rim thickness increases (Fig.8.2.5.1). Eskimos are the striking exception; they show as high a tendency for foramen of Huschke occurrence as Andamanese and Gabon, despite having by far the thickest tympanic rim of all modern human groups. This suggests that another important factor besides tympanic thickness is involved in the occurrence of this feature.

No foramen of Huschke was found in the ape sample (Table 8.5). In the *H.erectus* casts and from the literature, only *Sinanthropus* Skull IIIE shows a comparable feature; the tympanic deficiency appears on both sides and has been likened to the foramen of Huschke, but may correspond more closely to a marginal groove or foramen. Certainly in Skull IIIE the deficiency is not associated with a thin tympanic plate. Examples of the occurrence of tympanic plate dehiscence in apes, *H.erectus* and modern humans are pictured in Plate 8.5, p.333.

8.2.2.6. TEGMEN TYMPANI

The inferior projection of the tegmen tympani through the squamotympanic (Glaserian) fissure was found to be entirely absent in the *Gorilla/Pan* sample (Table 8.5). Aiello and Dean attribute this (usual) absence to early fusion in apes of the relevant sutures (Aiello & Dean, 1990:45). Tegmen tympani was not mentioned as a structure present in *H.erectus* in the literature and no sign of it is evident in the casts, but this may not be the case in the original material.

In 14.7% of the modern human sample, the tegmen tympani is completely absent; in 46.5% it is present and wider than 1mm. (Table 8.4). Andamanese crania have a particularly wide tegmen tympani, 76.2% being wider than 1mm., and Gabon has by far the highest % absence of tegmen tympani (43.0%).

For all but Andamanese there is a positive association between cranial size and tegmen tympani width (Fig.8.2.6.1). There is no obvious link between tegmen tympani width and tympanic rim thickness (Fig.8.2.6.2).

SUMMARY

The observations of this feature in apes and modern humans is consistent with the primitive condition being absence of a protruding tegmen tympani. However, insufficient information was available for comparison of the ape and modern human conditions with that of *H.erectus*. In the modern human sample 5 of the 6 groups show a positive link between tegmen tympani width and cranial size. Contrary to this, however, the Andamanese, the group with the smallest cranial size, has the highest % of tegmen tympani wider than 1mm.

Protrusion of the tegmen tympani may be a response to pressure on the endocranium from a "tightly fitting" brain. Certainly, parietal bosses, also characteristic of Andamanese, are consistent with the endocranium being under pressure from the brain. The lack of tegmen tympani in small brained apes compared to the frequent occurrence in large brained humans also lends support to the view that endocranial pressure due to brain expansion leads to increased protrusion of tegmen tympani through the squamotympanic (Glaserian) fissure to the external surface of the cranial base.

8.2.2.7 SUMMARY: DESCRIPTIVE FEATURES

None of the 6 descriptive features considered can be considered autapomorphic traits of Asian *H.erectus* or of *H.erectus* in general. All occur in modern humans and are either probably retained primitive features, occurring in apes as well as *H.erectus* (mastoid fissure, convex medial tympanic region) or they are derived features shared with both African and Asian *H.erectus* (medial recess). Supratubalis process and tegmen tympani could not be adequately assessed for *H.erectus* from the casts.

MASTOID FISSURE occurs in apes and in a third of modern humans but with unequal frequency in different populations. It is most common in Gabon and Eskimo and particularly rare in Poundbury (the group tested by Kennedy for mastoid fissure occurrence, 1991:401). The mastoid fissure is very variable in size and shape in both *H.erectus* and modern humans, but is generally wider and deeper in *H.erectus*. At least in modern humans, the feature tends to occur slightly more or is more prominent on the right side.

A negative link between cranial base flexion and mastoid fissure incidence in modern humans suggests flatness in the cranial base may be one factor in the occurrence and degree of expression of the feature. This was not quantitatively tested for *H.erectus*. In terms of occurrence of mastoid fissure, Australians are the second most dissimilar modern human group to *H.erectus*; relative to cranial base flexion they differ most in this feature.

MEDIAL RECESS is difficult to define quantitatively. As defined in this study, such a recess occurs in both African and Asian *H.erectus* but is not found in apes; in 28.6% of modern humans a recess >0.5 mm. does occur, but in only 7.7% is the recess wider than 1 mm. As in *H.erectus*, considerable variability is involved in its expression in modern humans but even more so in the reason for its absence, which may involve a simple pressing together of tympanic, entoglenoid and possibly sphenoid surfaces, or an intricate interlocking of projections from these surfaces. Australians and Andamanese,

having noticeably lowest incidence of medial recess, are the modern humans least like *H.erectus* in this feature. Australians are also the most dissimilar modern humans to *H.erectus* with regard to the associated structure of sphenoid spine. The feature is absent in nearly every *H.erectus* case, but among modern humans it is usually present and occurs most frequently in Australians. In both presence of medial recess and absence of sphenoid spine Gabon crania are the modern humans most similar to *H.erectus*.

Evidence was found of a negative association between medial recess occurrence in modern humans and anterior/posterior compression of the glenoid fossa (probably related to cranial base compression), but no link was found with cranial base flexion.

CURVATURE OF THE MEDIAL REGION OF THE TYMPANIC PLATE

The condition usual in *H.erectus* of a convex or a straight tympanic medial region is also found in modern human groups, though for all but Andamanese, the concave condition is far more common. Within the modern human sample there was no evidence to suggest that medial tympanic convexity is related to tympanic plate thickness. Andamanese with by far the highest incidence of convexity have the thinnest tympanic plate lateral rim, and Eskimos with the highest incidence of concavity have by far the thickest tympanic lateral rim.

SUPRATUBALIS PROCESS is a universal and prominent feature in apes; it is present also in about half modern human crania, but much reduced in length and robusticity. Although reportedly a feature of *H.erectus*, a meaningful comparison with the *H.erectus* condition could not be made from the casts or descriptions in the literature. Of the modern human groups, the feature is absent most frequently in Chinese and Poundbury and present most frequently in Eskimos and Australians, the 2 groups associated with most robust crania and thickest tympanic lateral rims. However, in modern humans in general, there was no link found between tympanic plate thickness and supratubalis process incidence.

Presence of the 2 remaining features may be autapomorphic for modern humans, but to assess if that is the case, data of

frequency of occurrence in other hominids would be needed.

FORAMEN OF HUSCHKE is not present in apes nor evident in *H.erectus* except possibly the Sinanthropus IIIE juvenile or adolescent specimen. The feature occurs in a fifth of modern humans, the least incidence being found in Australians and Poundbury crania. With the notable exception of the Eskimo group, a negative association between foramen of Huschke presence and tympanic rim thickness was found to exist for modern humans.

TEGMEN TYMPANI The feature is absent in apes; the condition in *H.erectus* cannot be determined from casts or the literature. In modern humans, the highest incidence of tegmen tympani occurs in Andamanese, the lowest in Gabon.

8.2.3 QUANTITATIVE FEATURES

Distribution of variation in each of the remaining 18 craniometric features is depicted in box plots (Figs.8.2.3.1-18). For ease of comparison, the recent modern groups are arranged in the box plots in order of increasing cranial size; the fossil Australians, Kow Swamp (10-13 ka), and Kanalda (approximately 14 ka), are plotted beside the recent Australians. Means and standard deviations for the 18 craniometric measurements are recorded in Appendix Tables A.8.3 for Gorilla, Pan and the various H.erectus groups, and A.5.1 for modern humans.

The Scheffe Test in One-way Analysis of Variance was used to detect if a significant difference in means exists within and between major groupings (significant at $p < .001$). However, it must be stressed that caution is needed in interpreting the results since

(i) samples other than those of recent modern humans, are very small and

(ii) *H.erectus* measurements are taken from casts, though when possible, values have been checked for consistency with comparable measurements taken on original material and recorded in the literature.

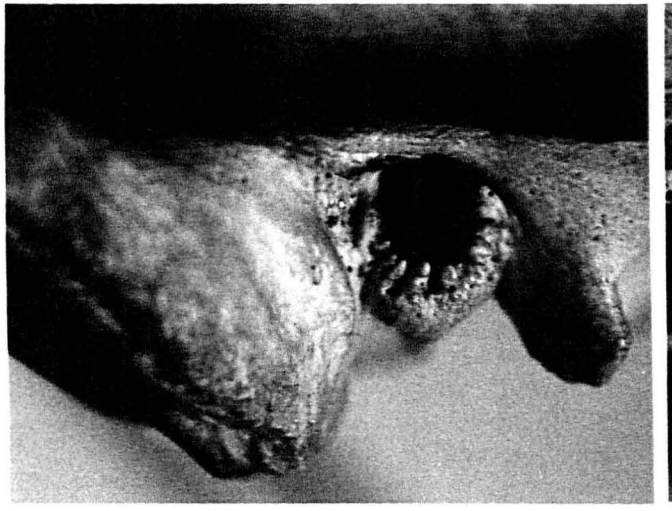
8.2.3.1-3 FEATURES IN WHICH ASIAN *H.ERECTUS* DIFFERS FROM AFRICAN *H.ERECTUS*: If Asian *H.erectus* differs significantly from African *H.erectus* and apes in a particular feature, and Australian and/or Chinese are the most similar of the modern groups to the Asian *H.erectus* expression of the feature, then this offers support for regional continuity and the multiregional theory of origins of modern humans.

8.2.3.1 TYMPANIC RIM THICKNESS Asian *H.erectus* tympanic rim is significantly thicker than that of African *H.erectus*, African apes and all modern humans except Eskimos and Australians (Fig.8.3.1.1-3). Although Eskimo and Australian crania are more like Asian *H.erectus* in this feature than are other modern humans, Eskimos must be seen as more similar to the Asian *H.erectus* condition than Australians. The Australian mean is at least as close to those of other modern groups as to any Asian *H.erectus* mean, whereas the Eskimo mean is closer

Plate 8.6
TYMPANIC PLATE LATERAL RIM THICKNESS

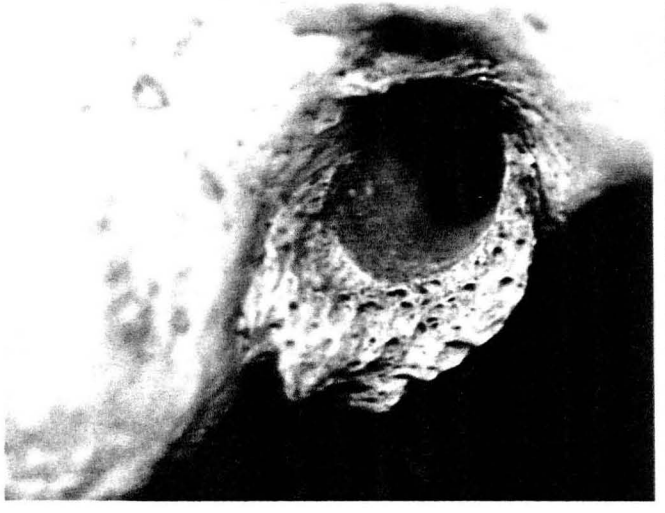
According to group means, the Eskimo tympanic lateral rim (c) is not only thicker than all other modern human groups but also thicker than that of African apes (a) and *H.erectus* (b). The thinnest tympanic rims occur in Andamanese (e). The Australian rim (d) tends to be thicker than that of other modern human groups except Eskimos.

a) *GORILLA*, o (1192)

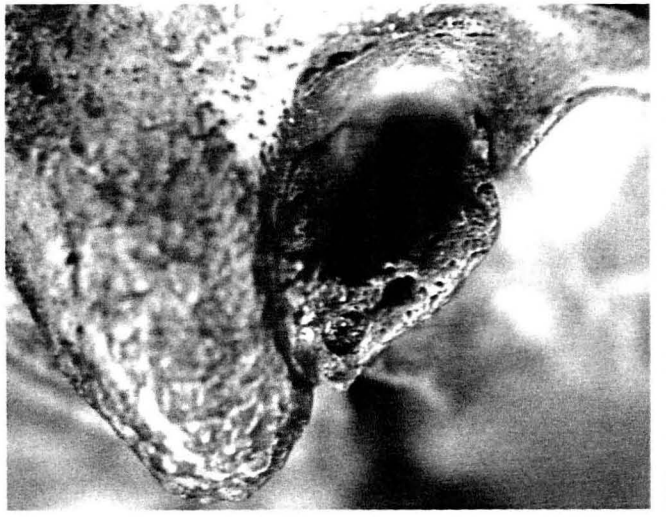


b) NGANDONG 7

c) ESKIMO (FC813)



d) AUSTRALIAN (30/437)



e) ANDAMANESE (1905.11/25/2)

to those of Asian *H.erectus* groups than to any modern group means; the Eskimo mean is the largest of all and significantly larger than that of all groups except Asian *H.erectus*. Chinese crania are dissimilar to the Asian *H.erectus* condition for this feature, the Chinese mean being significantly less than that of not only Asian *H.erectus* and Eskimos but also Australians. Some aspects of variation in tympanic plate rim thickness in apes, *H.erectus* and modern humans are evident in Plate 8.6.

A particularly thick tympanic rim could well be derived for Asian *H.erectus* but a similar analysis of data from other hominid groups (australopithecines, Early *Homo*, Archaic *H.sapiens*) would be helpful in assessing this aspect. Despite the significant differences that exist between group means for tympanic rim thickness, the range of variation observed in African and Asian *H.erectus*, *Gorilla* and *Pan* lies within the total variation range of modern humans. This pattern of variation of rim thickness does not necessarily correspond to that for thickness in the medial region of the tympanic.

In the analysis of variation of this tympanic rim thickness in modern humans, it was found that as the tympanic rim becomes thicker, the maximum cranial breadth is positioned closer to the base (Fig.8.3.1.2); Australians and particularly Eskimos with the thickest tympanic rims tend to be most "tent-shaped". Asian *H.erectus* show the same relationship, but the 3 African *H.erectus* and the apes have markedly thinner tympanic rims in relation to their cranial breadth proportions (Fig.8.3.1.3). Kennedy (1991:404,405) pointed out that the thickness in *H.erectus* cranial vault is partly because of the pneumatization of the temporal bone including even the temporal squamous. It is reflected in a thickened *pars tympanica* and in the characteristic *H.erectus* tent-shape, and Kennedy suggested that the cranial breadth index may give a measure of the degree of pneumatization. The results of this study support this proposal and extensive pneumatization of the temporal bone, including the temporal squamous, was observed in a number of Eskimo crania (Plate 8.7). Kennedy regarded such pneumatization as a symplesiomorphic process.

8.2.3.2 TYMPANIC RIM INDENT The tympanic rim indent as defined in Section 4.2.2 & Appendix Table A.4.10 is equivalent to the wide "roof" of zygomatic crest overhanging the external

Fig.8.3.1.1 Tympanic Rim Thickness

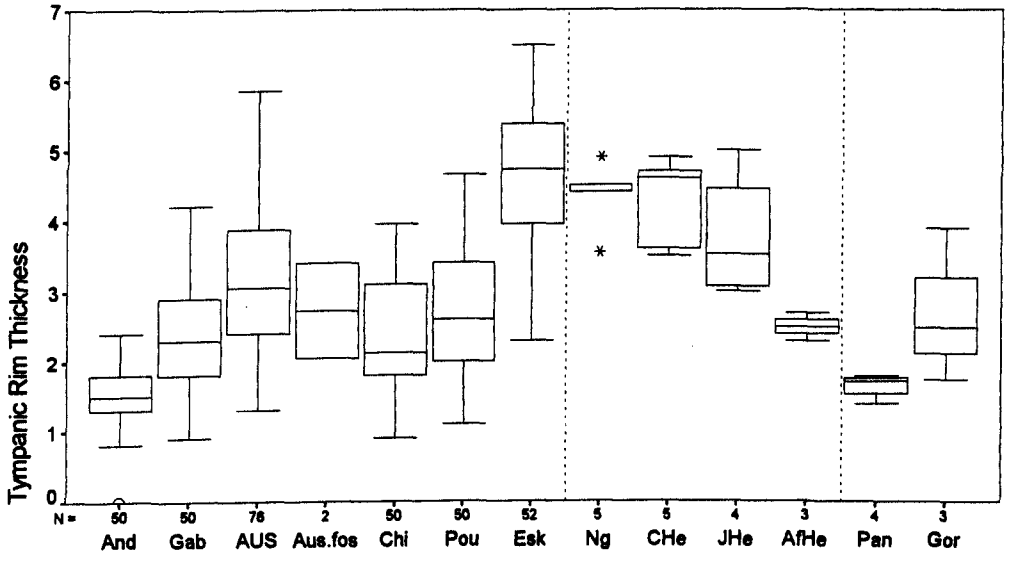
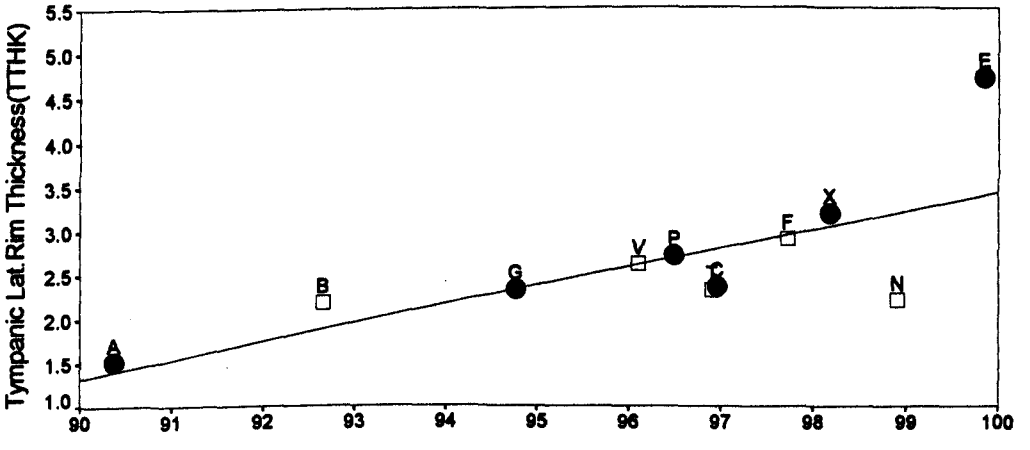


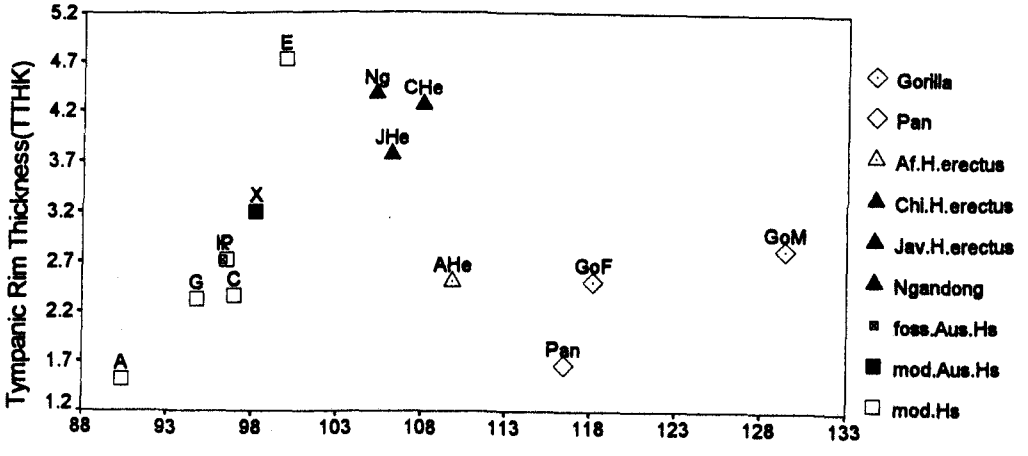
Fig.8.3.1.2 Tympanic Rim Thickness vs. Cranial Breadth Ratio



TTHK = .210 SCXCB -17.65, R= .72, p= .013 (r = .42, p = .001)

A thick tympanic rim corresponds to a low maximum cranial breadth.

Fig.8.3.1.3 Tympanic Rim Thickness vs. Cranial Breadth Ratio



In modern humans & Asian H.erectus TTHK increases as SXCB increases. For their SCXCB dimensions,African H.erectus & ape rims are thin, Esk.thick.

acoustic meatus noted by Weidenreich as a difference between *Sinanthropus* and modern humans (Weidenreich 1943:53). As a measure of this "overhang", he gave the distance between the auriculare plane and the most lateral point of the porous edge as 10-15mm. in *Sinanthropus* and "hardly ever" more than 10mm. in modern humans. Such a trend was confirmed in this study, though with somewhat greater overlap between the Asian *H.erectus* and modern human range of variation.

The tympanic rim indent or "overhang" was found to be particularly large in Asian *H.erectus*, and may well be the derived condition (Fig.8.3.2). The indent means of Asian *H.erectus*, Chinese, Andamanese and Poundbury groups are significantly greater than those of African *H.erectus*, apes and Gabon. The tympanic rim is significantly less indented for *Pan* and *Gorilla*, than for all *H.erectus* and recent modern human groups. The Australian mean is intermediate in the modern human distribution range and closer to the means of other modern groups and African *H.erectus* than to any Asian *H.erectus* group mean.

The Chinese group is closest of all modern groups to the Asian *H.erectus* condition; its mean is not significantly different to any Asian *H.erectus* group mean and is significantly greater than some modern group means including that of Australians. However, modern Chinese and Asian *H.erectus* appear to differ as to the main factors determining their comparatively deeply set external acoustic meatus. Prominence of the suprameatal crest and thinness of the tympanic plate both contribute to a deep rim indent; in Asian *H.erectus* an extremely prominent suprameatal crest is the predominant factor, whereas in Chinese crania the thinness of the tympanic rim appears to be more important. Australians with opposing factors of prominent suprameatal crest and thick tympanic rim, have small indent.

8.2.3.3 GLENOID FOSSA LENGTH/WIDTH RATIO *H.erectus* glenoid fossa has been described as transversely wide, short antero-posteriorly and deep. According to group means, the glenoid fossa length to width ratios of *Gorilla* and *Pan* are significantly less than those of all other groups; the ratio mean in Asian *H.erectus* is significantly greater than that of African *H.erectus* and the expression in Asian *H.erectus* may be the derived condition (Fig.8.3.3). Of the modern humans,

Fig.8.3.2 Tympanic Rim Indent

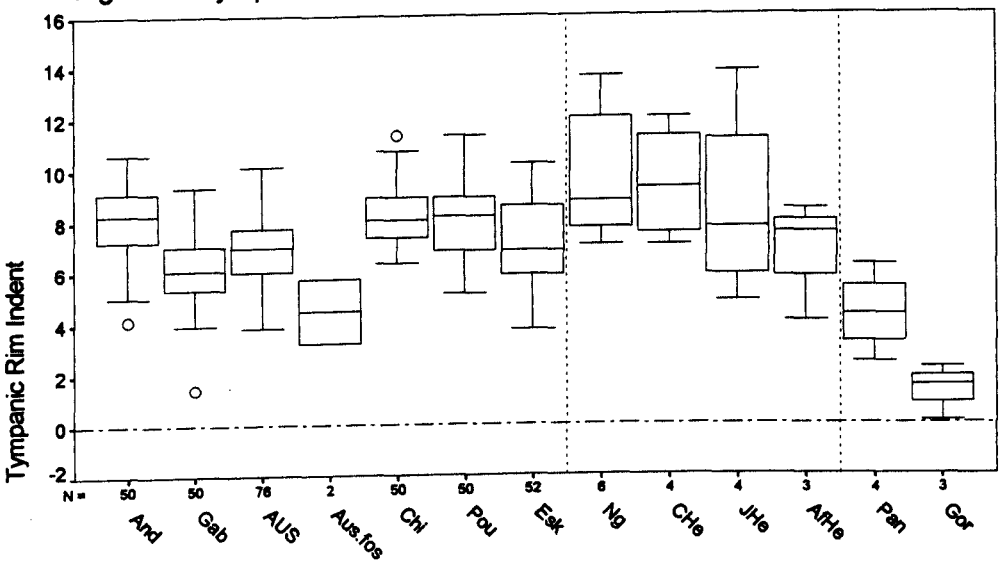


Fig.8.3.3 Glenoid Fossa ant-post/med-lat.Ratio

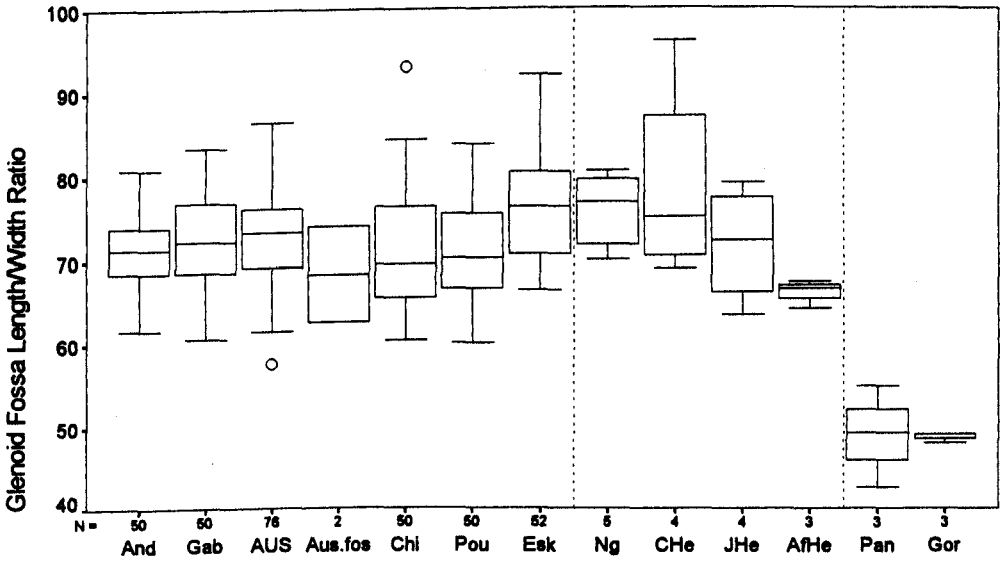


Fig.8.3.4 Occipital/Nuchal Sagittal Chord Ratio

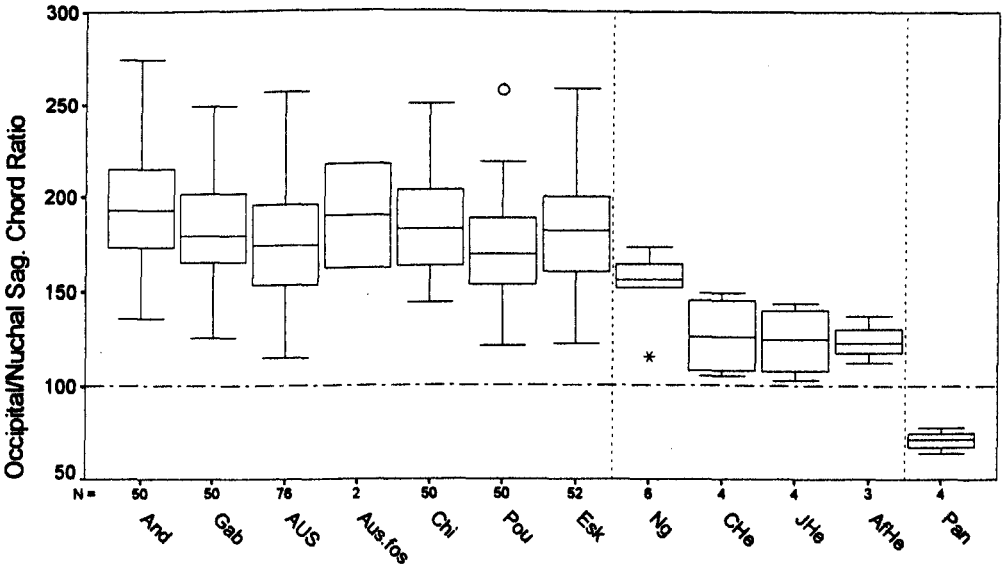


Fig.8.3.5.1 Suprameatal Crest Angle

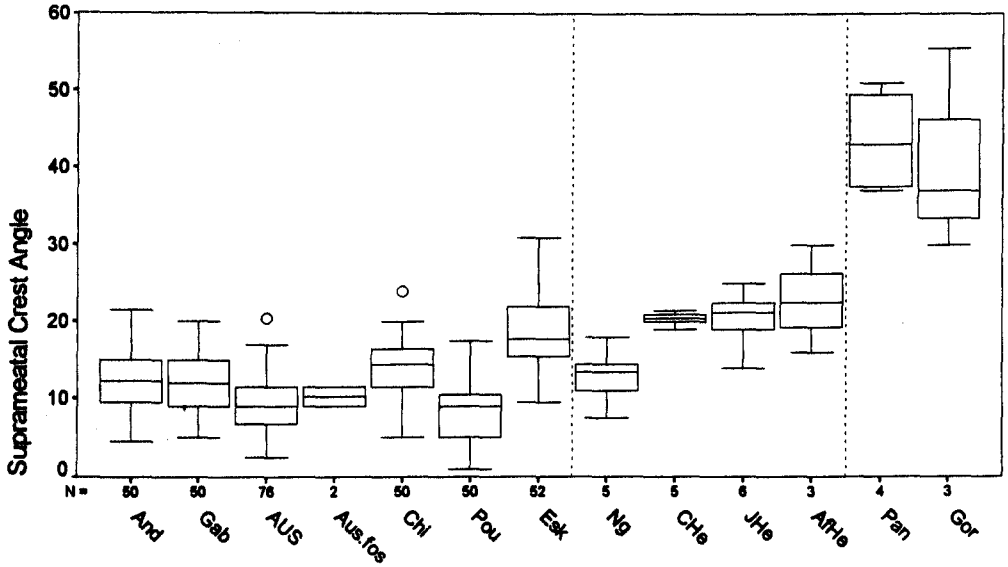


Fig.8.3.5.2 S'meatal Crest Angle vs.Cranial Breadth/Length Ratio

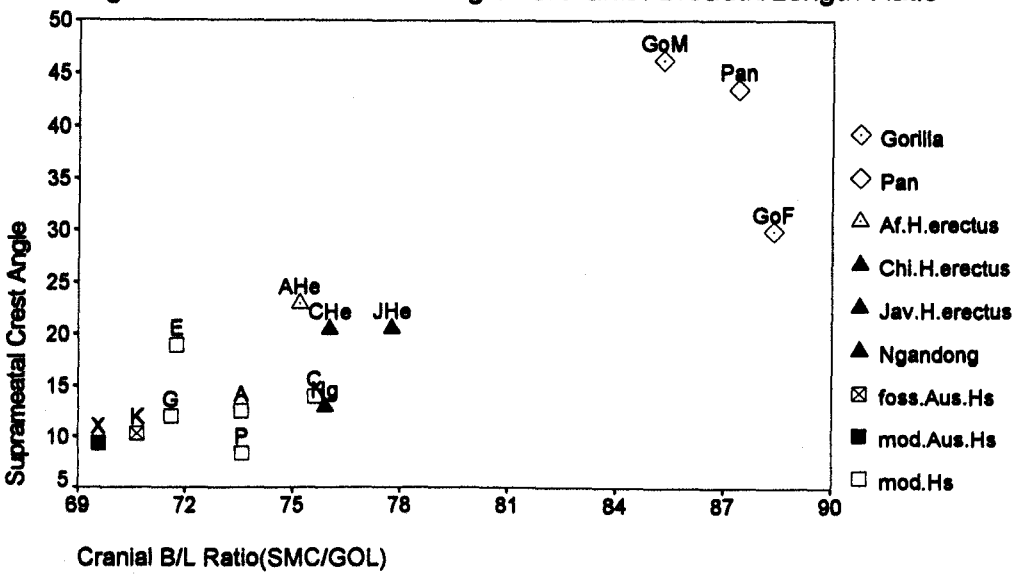
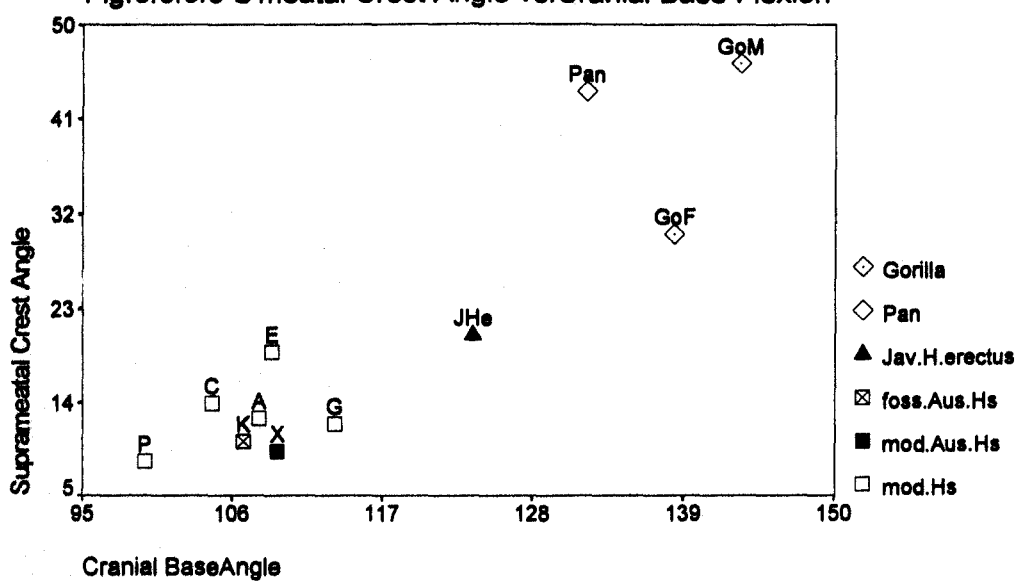


Fig.8.3.5.3 S'meatal Crest Angle vs.Cranial Base Flexion



Eskimo and Australian means are closest to that of Asian *H.erectus* though there is considerable overlap of distribution ranges of *H.erectus* groups with all modern groups. The Eskimo mean is significantly greater than those of all modern groups including Australians. The Chinese mean is intermediate among the modern means.

8.2.3.4-7

FEATURES IN WHICH NGANDONG DIFFERS FROM OTHER *H.ERECTUS*

Since Ngandong is significantly different to the other *H.erectus* groups in these features, a pattern of variation which shows Australians are more similar to the Ngandong expression of the feature than are other modern human groups, would offer support for regional continuity.

8.2.3.4 OCCIPITAL/NUCHAL SAGITTAL CHORD RATIO This ratio could not be measured for *Gorilla* since lambda can not be determined in gorilla crania. The length of the upper plane of the occipital bone increases relative to the length of the lower nuchal plane from *Pan* to *H.erectus* to modern humans, the primitive condition being a low ratio (Fig.8.3.4). The *Pan* mean is significantly less than all other group means and only in *Pan* is the ratio < 100 i.e. the lower nuchal plane is sagitally longer than the upper occipital plane.

Excluding Ngandong, the mean of *H.erectus* groups combined is significantly smaller than any modern human group mean. The Ngandong distribution is intermediate between modern humans and the other *H.erectus* groups. The Ngandong mean is larger than any other *H.erectus* mean and smaller than any modern group mean but not significantly so in any case.

Of the modern human groups, Australian and Poundbury are most similar to Ngandong in this feature; the Poundbury mean is slightly closer to that of Ngandong than the Australian mean. But for both groups the resemblance is greater with other moderns than with Ngandong.

8.2.3.5 SUPRAMEATAL CREST ANGLE. (Figs.8.3.5.1-3) In *Pan* and *Gorilla* the suprameatal crest is significantly more vertically oriented than in *H.erectus* or modern human groups (Fig.8.3.5.1). The means of Eskimos and all *H.erectus* groups except Ngandong are significantly larger than all other modern humans. This suggests that Eskimos are more similar in this feature to *H.erectus* than to other modern humans, but there is

considerable overlap between the Eskimo range of variation and that of other modern human groups.

The Ngandong mean is significantly smaller than that of other *H.erectus* groups and Eskimos, and shows the usual modern human and possibly derived condition of a more horizontally inclined suprameatal crest. If Weidenreich is correct in thinking the suprameatal crest inclination is positively linked to size of face relative to calvarial size (Weidenreich 1943:43), this result may indicate a face size in Ngandong considerably reduced from that of other *H.erectus*, and comparable to modern face to vault proportions. Of modern human groups, the Chinese are most similar to Ngandong in this feature, while Australian and Poundbury crania, having the most horizontally inclined suprameatal crests, are least like *H.erectus* and furthest from the apparently primitive condition of a vertically tending suprameatal crest angle.

At least across the species, length of skull relative to breadth and cranial base flexion appear to be two contributing factors in determining the suprameatal crest orientation. Comparison of modern human group means with those of *H.erectus* and apes indicates that the suprameatal crest becomes increasingly horizontal as cranial length decreases relative to cranial breadth (Fig.8.3.5.2) and as the base becomes more flexed (Fig.8.3.5.3).

8.2.3.6 PETROUS-TYMPANIC ANGLE (Fig.8.3.6.1-9). The angle between the petrous and tympanic axes increases from apes to *H.erectus* to modern humans; the primitive polarity is an acute petrous-tympanic angle (Fig.8.3.6.1 and Plate 8.8). *Gorilla* and *Pan* means are significantly smaller than all other group means. The quantitative results agree well with those of Dean and Wood (1982:159,161); although the tympanic angle used in this study does not coincide exactly with their definition, the differences in the petrous-tympanic angle means between apes, *H.erectus* and modern humans are comparable.

Excluding Ngandong, the mean of *H.erectus* groups combined is significantly less than any modern human group mean. The Ngandong distribution is intermediate between modern humans and the other *H.erectus* groups; the Ngandong mean is larger than any other *H.erectus* mean and smaller than any modern group mean but not significantly so in any case.

Of the modern humans, Australians (fossil and recent) are

Plate 8.7 TEMPORAL SQUAMOUS PNEUMATIZATION

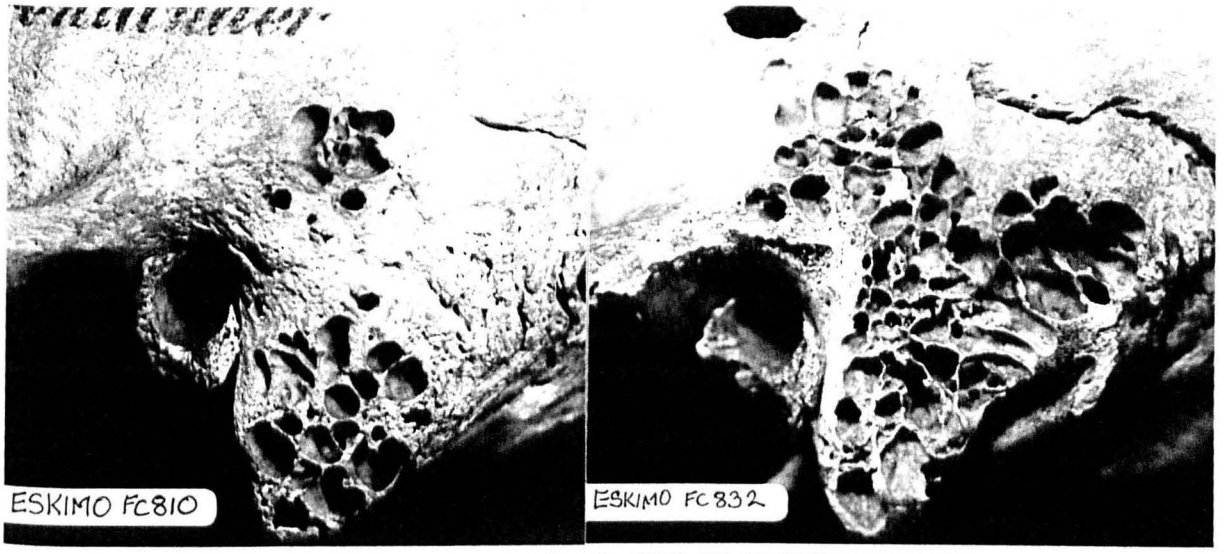


Plate 8.8 PETROUS-TYMPANIC ANGLE
IN APES, *H.ERECTUS*, AND MODERN HUMANS

The angle between the petrous and tympanic axes increases from apes to *H.erectus* to modern humans as cranial base flexion increases, petrous and tympanic length decrease and cranial breadth to length decreases.

a) Gorilla [O, 1192]

b) Ngandong 7

c) Modern Australian [1937:2/5/1]

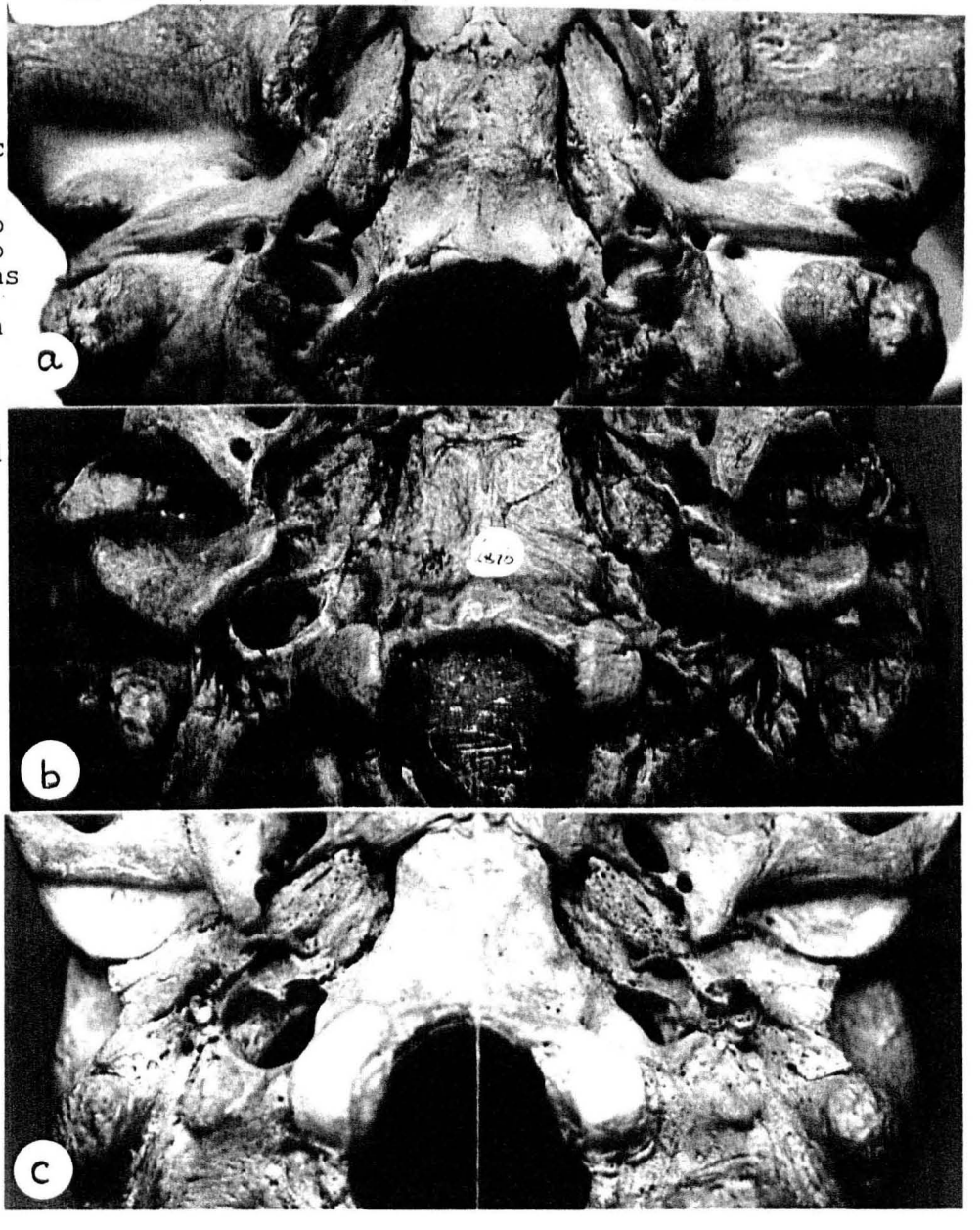


Fig.8.3.6.1 Petrous-Tympanic Axis Angle

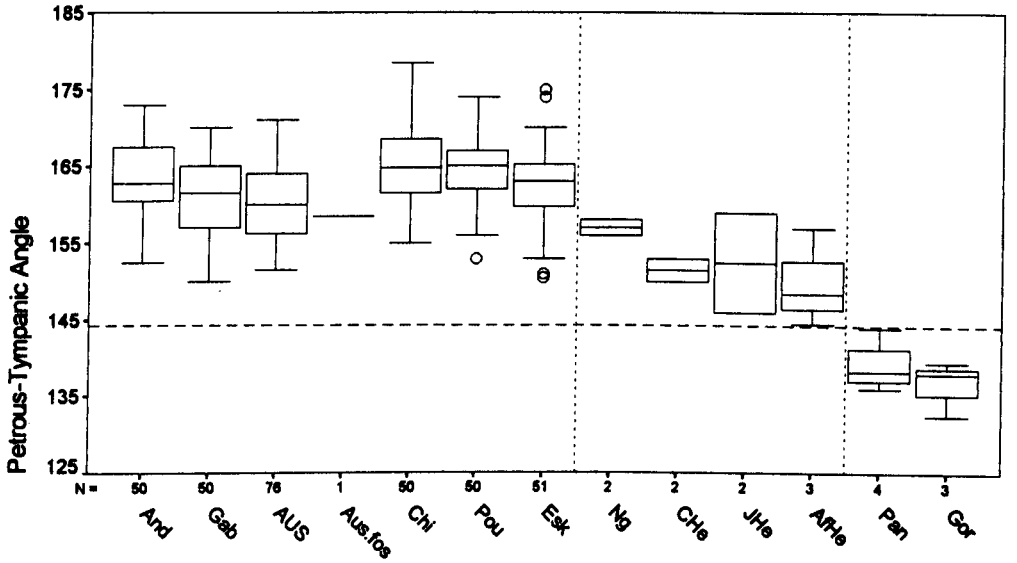


Fig.8.3.6.2 Petrous-Tympanic Angle vs. Cranial Base Flexion

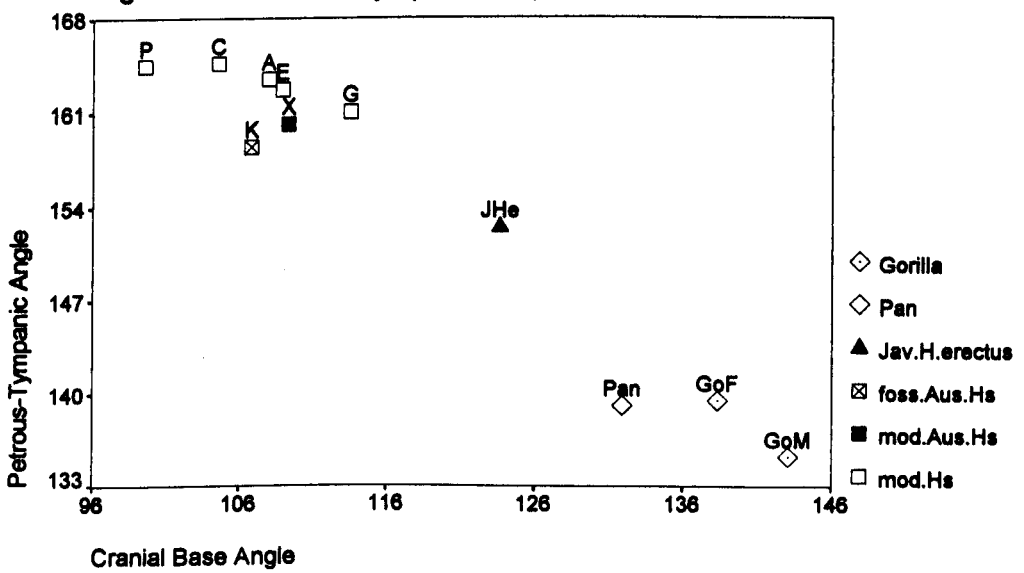


Fig.8.3.6.3 Petrous-Tympanic Angle vs. Petrous Pyramid Length

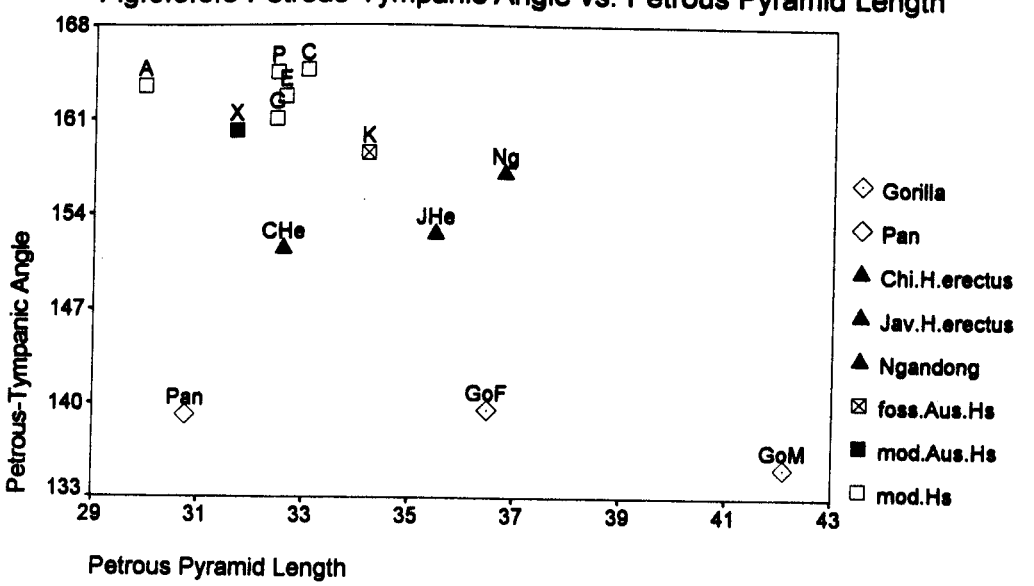


Fig.8.3.6.4 Petrous-Tympanic Angle vs. Tympanic Plate Length

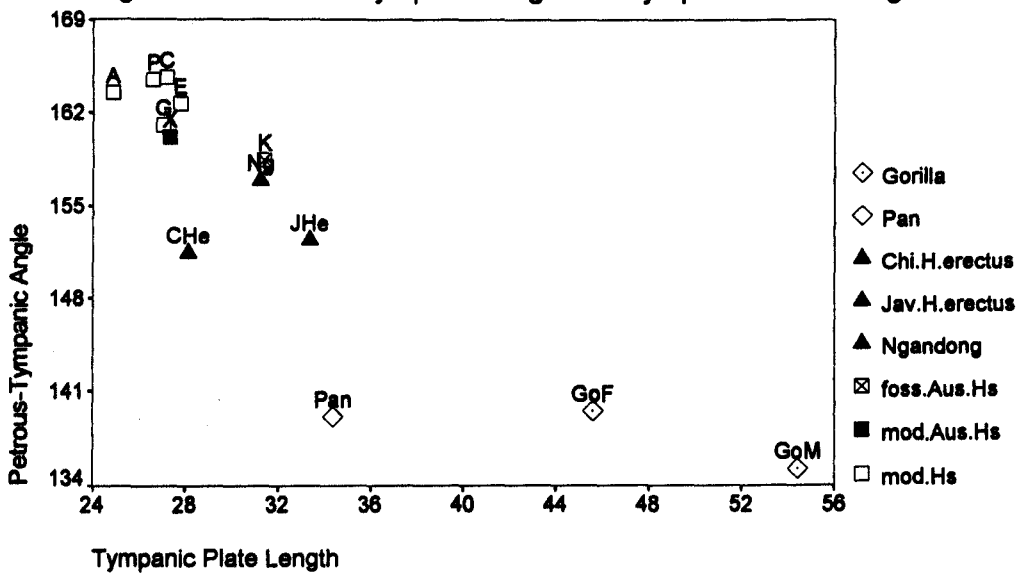


Fig.8.3.6.5 Petrous-Tympanic Angle vs. Cranial Breadth/Length Ratio

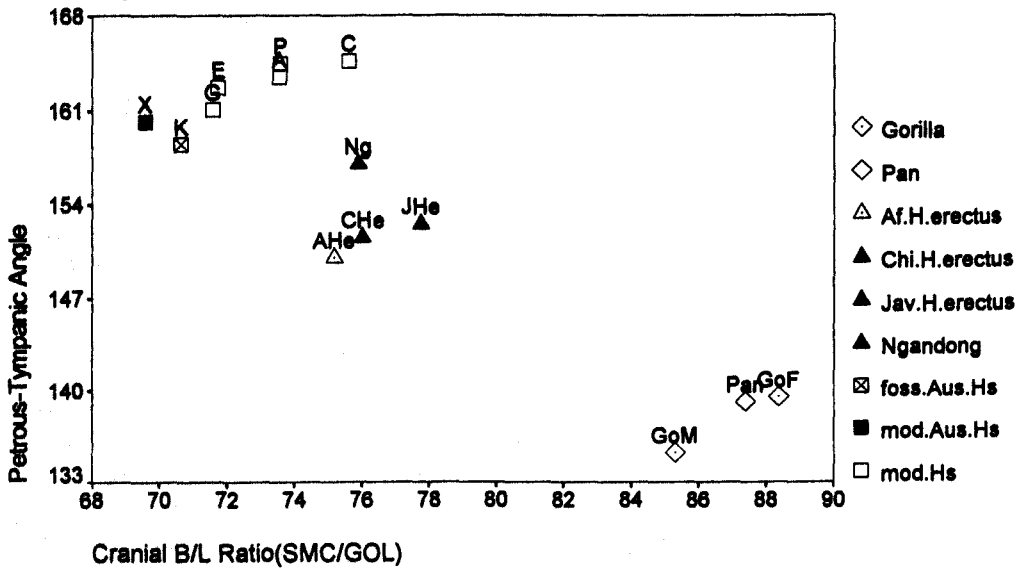
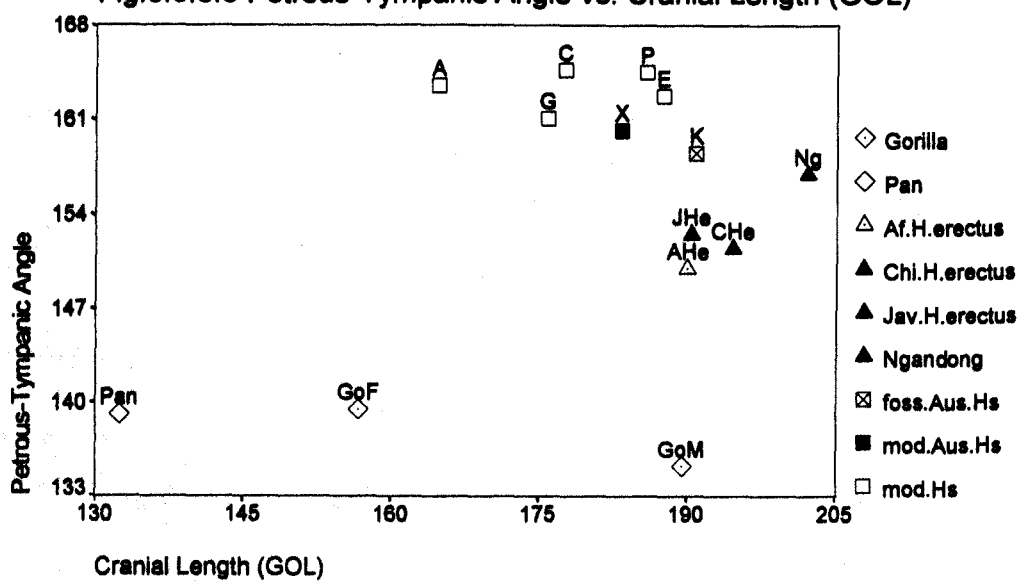


Fig.8.3.6.6 Petrous-Tympanic Angle vs. Cranial Length (GOL)



most similar to Ngandong in this feature; Chinese and Poundbury, with the largest means, are least like Ngandong and other *H.erectus* groups, and furthest of the modern humans from the primitive expression of an acute petrous-tympanic angle. The means of both groups are significantly greater than the Australian mean, which is closer to that of Ngandong.

There is possible support for regional continuity in the Australians being slightly more similar than other modern groups to Ngandong in this feature, but not necessarily so; a genetic factor is not necessarily involved. A comparison with data from archaic *H.sapiens* and Ngandong contemporaries in other regions would be needed to reach a conclusion.

As noted in Section 8.1.1.4(17), several suggestions have been put forward to account for the increase in the petrous-tympanic angle from apes to *H.erectus* to modern humans including a positive association of the angle with one or more of the following features: decreased petrous length, decreased tympanic length, decreased cranial length absolutely and/or relative to cranial breadth, increased cranial base flexion and forward movement of the foramen magnum. There also exists a moderate negative correlation (at $p < .01$) of petrous-tympanic angle with mastoid transverse depth (Appendix Table A.5.2). To test these possible associations, group means for each of these 7 variables in turn were plotted with petrous-tympanic angle group means. The groups are the various modern human, *H.erectus* and ape groups represented in the box plots but male and female *Gorilla* data are plotted separately.

The results do support the suggestions that the petrous-tympanic angle increases from apes to *H.erectus* to modern humans as the cranial base becomes more flexed and as the petrous pyramid and tympanic plate shorten (Figs.8.3.6.2-4 respectively). However, the results also indicate that across the species as crania become shorter relative to their breadth, the petrous-tympanic angle decreases rather than increases as suggested (Fig.8.3.6.5). (A different result may have been obtained if a direct measurement of cranial base length rather than GOL had been used). Excluding apes, the petrous-tympanic angle tends to increase from *H.erectus* to modern humans, as cranial absolute length (GOL) decreases and as mastoid transverse depth decreases (Figs.8.3.6.6 & 7 respectively).

No simple pattern is evident of the petrous-tympanic angle increasing as the foramen magnum migrates anteriorly (Figs.8.3.6.8 & 9). If the anterior-posterior position of foramen magnum is measured relative to the bitympanic line, neither the foramen magnum centre nor basion are positioned more posteriorly from modern humans to *H.erectus* to apes. Certainly basion is placed noticeably more posteriorly in apes than modern humans, but it is at least as anteriorly placed in *H.erectus* as in modern humans; also, the centre of the foramen magnum is as anteriorly placed in *Pan* and Javan *H.erectus* as in modern humans. Consequently, while the petrous-tympanic angle increases as basion anteriority increases from apes to modern humans, it becomes more acute with increasing basion anteriority from modern humans to *H.erectus*. No relationship was detected between the petrous-tympanic angle and the position of the foramen magnum centre.

The same patterns of petrous-tympanic angle variation with cranial base flexion, mastoid depth and cranial length observed between the species (Figs.8.3.6.2,6 & 7) are evident also when only modern human group means are compared. Petrous-tympanic angle is independent of cranial length but increases in modern humans as the base becomes more flexed ($r= -.18$, $p<.01$) and the mastoid becomes smaller transversely ($r=-.233$, $p<.01$) (Appendix Table A.5.2).

In the asymmetry analysis in Section 4.4.2 it was shown that for modern humans there may be a positive connection between jugular fossa size and petrous-tympanic angle, both features being larger on the right side. Weidenreich found the same jugular fossa asymmetry in *H.erectus* and noted also that the jugular fossa is smaller in *H.erectus* than in modern humans (Weidenreich 1943:61;1951:279). This is consistent with a larger jugular fossa contributing to the increased petrous-tympanic angle in modern humans compared to *H.erectus* though further data from *H.erectus* would be needed to confirm this.

8.2.3.7 TYMPANIC AXIS SAGITTAL ANGLE (Fig.8.3.7). According to the group means there is a slight decrease in tympanic axis sagittal angle from apes and the older *H.erectus* groups to modern humans and Ngandong, suggesting the primitive polarity is for a more coronally aligned tympanic axis. But there is considerable overlap of variation ranges of groups within and

Fig.8.3.6.7 Petrous-Tympanic Angle vs. Mastoid Process Depth

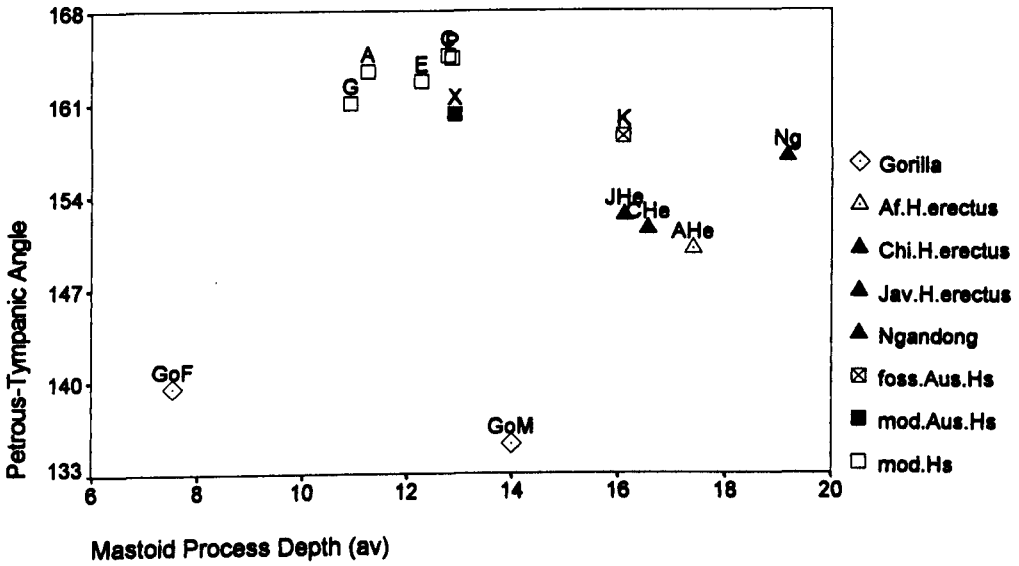


Fig.8.3.6.8 Petrous-Tympanic Angle vs. Anteriority of Basion

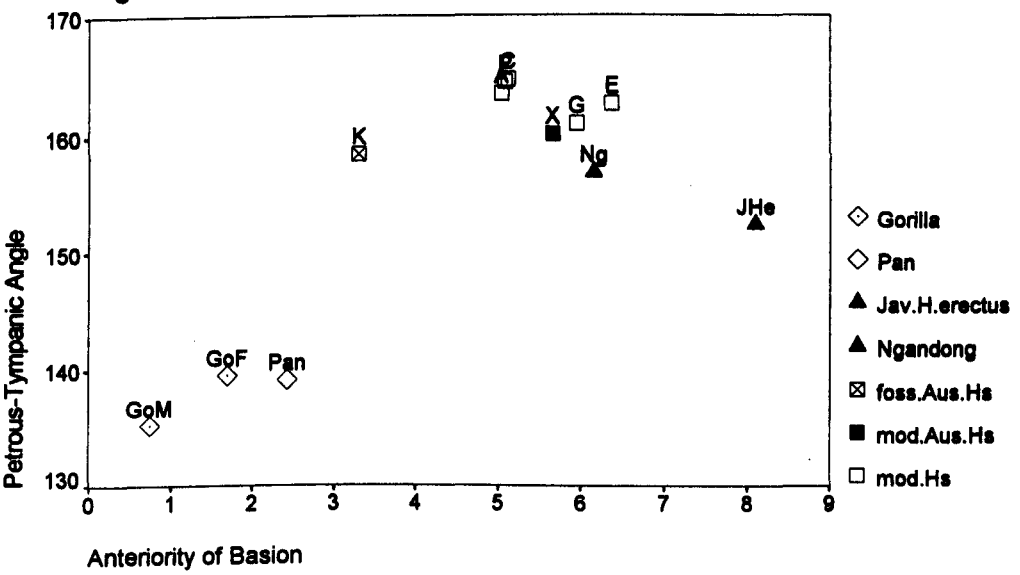


Fig.8.3.6.9 Petrous-Tympanic Angle vs. Posteriority of F.Magnum

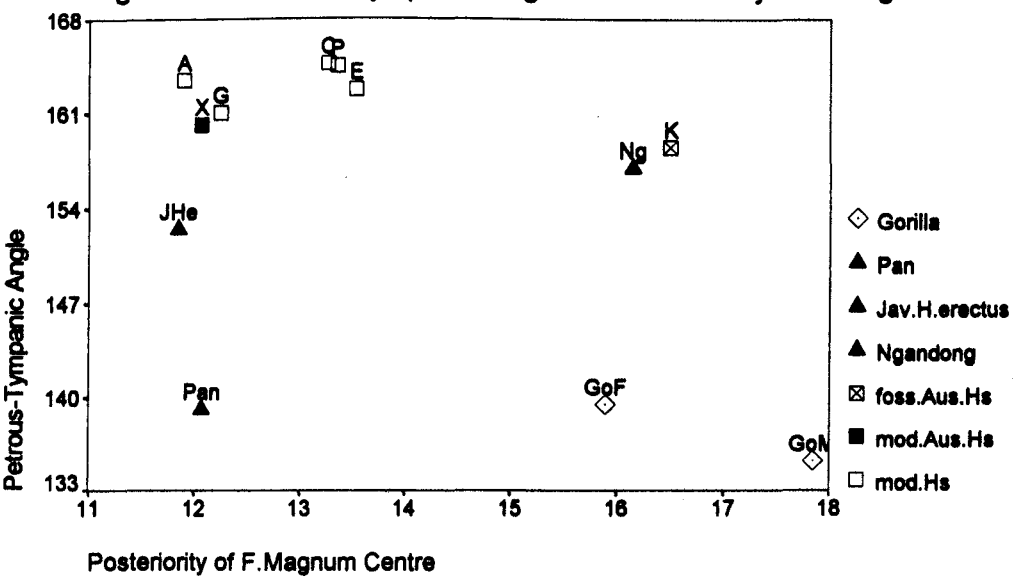


Fig.8.3.7 Tympanic Axis Sagittal Angle

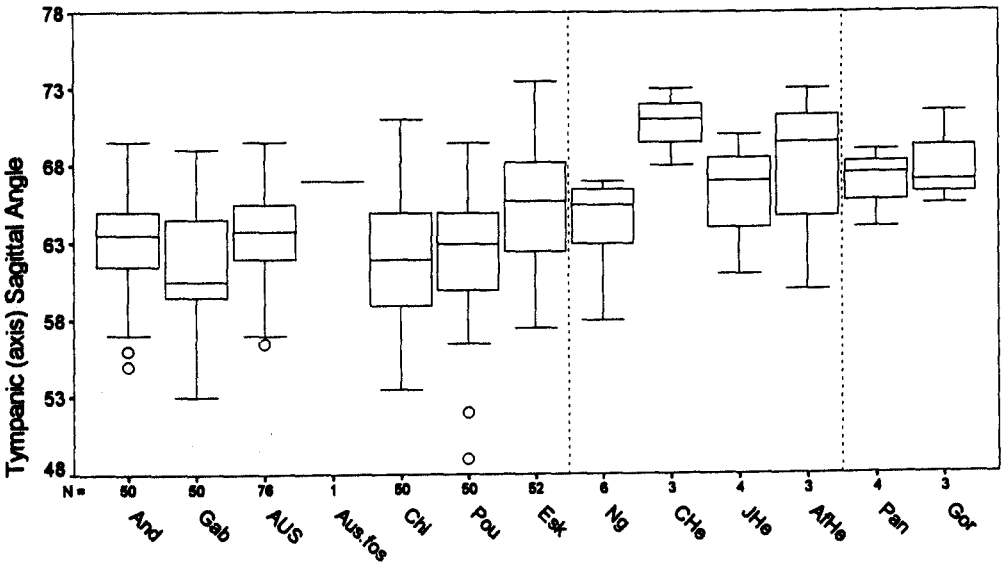


Fig.8.3.8 Occipital Chord/Arc Ratio

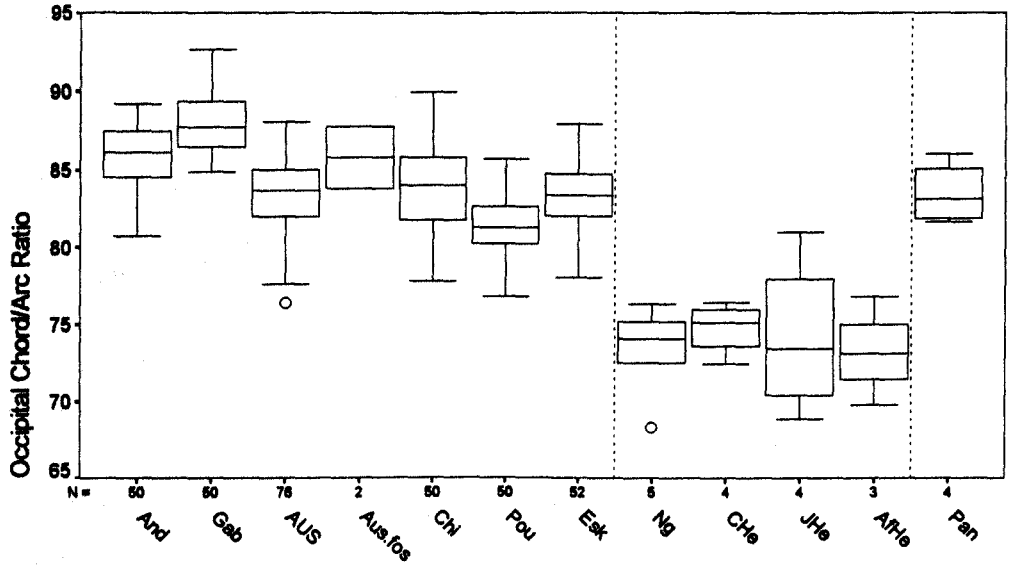
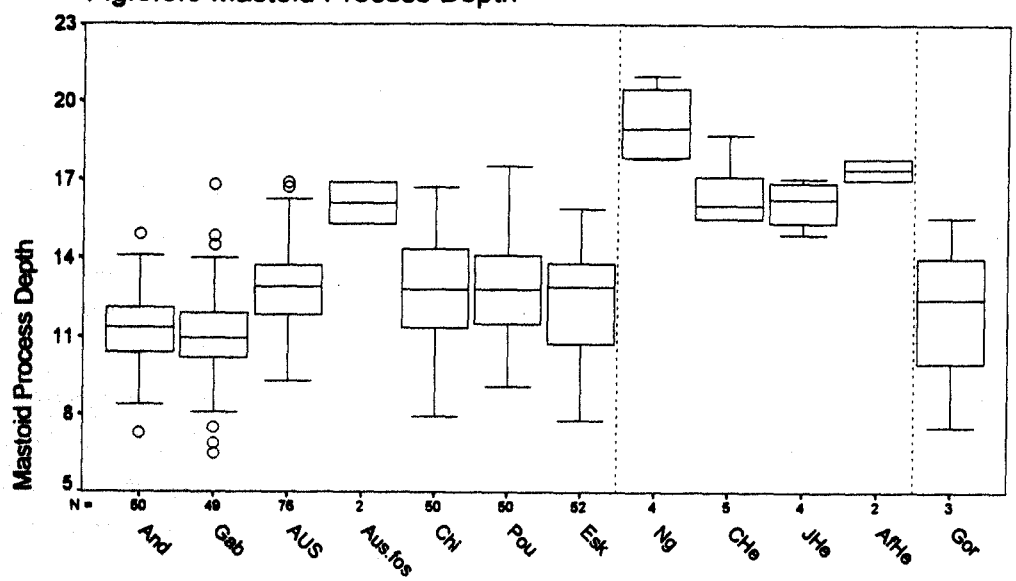


Fig.8.3.9 Mastoid Process Depth



between the 3 major groupings, and all *H.erectus* and ape group ranges lie within the total human range.

The tympanic axis is most coronally inclined in *Sinanthropus*, though the group mean is not significantly larger than any other single group. There is no significant difference between the means of *Pan* and *H.erectus*, African *H.erectus* and all other *H.erectus*, the 2 Javan *H.erectus* and African and Chinese *H.erectus*, Ngandong and the other *H.erectus* groups, or between Ngandong mean and any modern human group means. Excluding Ngandong, the combined *H.erectus* mean is significantly greater than those of only 3 modern groups -- Gabon, Chinese and Poundbury. It is noteworthy that the Chinese mean is the second smallest of modern human and all means and yet Chinese *H.erectus* has the largest mean; only Gabon is further removed than the modern Chinese from the *Sinanthropus* condition of most coronally inclined tympanic.

Within *H.erectus*, the Ngandong mean is closest to that of the other (older) Javan group; but it is even closer to 4 of the modern human group means. Australians and particularly Eskimos are the closest modern humans to the Ngandong and general *H.erectus* condition since they have the most coronally oriented tympanic axes of all modern groups. The Eskimo mean is even larger than that of Ngandong.

This trend is consistent with the finding in factor analysis (Section 6.2.1.2 & Figs.6.2.1.1 & 2) of a negative association for modern humans between tympanic axis sagittal angle and anteriority of basion and foramen magnum; the centre of the foramen magnum is located more posteriorly in Eskimo than in the 5 other modern groups. The factor may also operate between major groupings since there is a anterior migration of the foramen magnum and basion location from apes (possibly) to *H.erectus* to modern humans. The depth of the mastoid process is also a factor related to the tympanic axis orientation in modern humans, a moderately strong positive correlation existing between the 2 traits (Appendix Table A.5.2). This does not seem to apply in *H.erectus* groups since Ngandong crania have the deepest mastoid process but the smallest tympanic sagittal angle. Across species boundaries, it is consistent with *H.erectus* generally having a deeper mastoid process and more coronally oriented tympanic axes than modern humans, but it does not explain the position of African apes, noted for their

small mastoid processes but with tympanic axes as coronally oriented as in *H.erectus*.

8.2.3.8-10 FEATURES IN WHICH *H.ERECTUS* DIFFER FROM BOTH MODERN HUMANS AND APES IN THE SAME WAY.

In these features all *H.erectus* group means either exceed both modern human and ape means or are less than both modern human and ape means. Since no significant difference has been detected between African and Asian *H.erectus* in these features they are not useful in demonstrating possible regional continuity with any modern groups.

8.2.3.8 OCCIPITAL CHORD/ARC RATIO. (Fig.8.3.8) The occipital bone is more acutely curved in *H.erectus* groups than in *Pan* or modern humans. The ratio cannot be measured for *Gorilla* since lambda cannot be determined. All *H.erectus* group means are significantly less than that of *Pan* and of all modern human groups; the Pan mean is in the middle of the modern human range. According to group means, Poundbury approach the *H.erectus* condition more closely than any other modern group but is closer to modern groups than to any *H.erectus* group. The Chinese mean is intermediate in the total modern range.

The sharp occipital curve in *H.erectus* is evidently linked to the existence of the extremely prominent occipital torus in *H.erectus* crania, whereas for Poundbury a more likely association is with the comparatively high incidence of occipital bun observed in Poundbury crania. The Australian mean is second smallest of the modern human group means and from observation of the crania this most likely corresponds to the moderately high frequency of occipital torus and bun observed in Australians. The occipital is significantly flatter in Andamanese and Gabon than all other recent modern groups and both groups have negligible incidence of occipital tori or buns. However, the incidence of buns and tori has not been quantified in this study.

An occipital chord/arc ratio < approximately .77 may be a shared-derived trait of Asian and African *H.erectus*, but similar data about other hominids needs to be assessed before such a conclusion could be reached. Australians are not the modern humans most like *H.erectus* in this feature.

8.2.3.9 MASTOID PROCESS DEPTH. (Fig.8.3.9) The mastoid process is deeper in all *H.erectus* groups than in all recent modern humans groups and *Gorilla* (The condition could not be assessed in *Pan* because of the non-projecting nature of the process). Of the modern human groups, fossil and recent Australians have the largest mastoid depth means and so are most similar to *H.erectus* in this feature. The recent Australian mean is only marginally greater than that of other modern groups, whereas the Australian fossil mean (only 2 cases) is more similar to that of *H.erectus* than to any recent modern group mean, and is the only modern group mean not significantly less than the combined *H.erectus* mean. The *Gorilla* range of variation in mastoid depth lies within the total human range. In comparison to the condition in *Gorilla* and modern humans, a transversely deep mastoid process appears to be a shared derived trait of African and Asian *H.erectus*, but to confirm this, the condition in other hominids needs to be assessed. Even if a deep mastoid process is a synapomorphy of African and Asian *H.erectus*, the fact that fossil and recent Australians are most similar of the moderns in this feature to *H.erectus* neither supports nor refutes the multiregional proposal.

8.2.3.10 TYMPANIC (ANTERIOR SIDE) SAGITTAL ANGLE. When differences in orientation of the tympanic plate with respect to the mid-sagittal line have been referred to in the literature, the line taken to measure the angle involved have not been consistent. The measurement in this study, the angle the anterior side of the tympanic plate makes with the sagittal line, corresponds to that used by Weidenriech -- the direction of the Glaserian fissure, (Weidenreich 1943:53,58, 59). The pattern of variation observed in this analysis corresponds with and expands to other groups the trend he recorded for *Gorilla*, *Sinanthropus* and modern Europeans (Weidenreich 1943:58).

Tympanic Angle (mean)

Weidenreich: Europeans 78° ; *Sinanthropus* III 94° ; *Gorilla*(m) 88°
This study : Poundbury 78.8°; *Sinanthropus* (av) 95.5°; *Gorilla*(m) 76.3°

The anterior side of the tympanic plate is significantly more sagitally inclined in *Gorilla* and *Pan* than in *H.erectus* (Fig.8.3.10). It is more coronally inclined in Ngandong and

Sinanthropus (means >90°) than in African and Javan *H.erectus*, and more coronally inclined in all *H.erectus* groups than in any modern human group. The mean for combined *H.erectus* groups is significantly larger than all modern group means except that of Eskimos.

Of the modern humans, the orientation of the tympanic anterior side in Australian crania is comparatively intermediate, and that of Chinese and Andamanese is most sagitally oriented and thus least similar to the *H.erectus* condition. The Eskimo is closer to *H.erectus* in tympanic anterior orientation than to other modern humans; the Eskimo mean, with that of *H.erectus* is significantly greater than all other modern group means. There is considerable variation within and between the modern groups, and the distribution ranges of all non-modern groups except *Sinanthropus* lie within the total modern human distribution range.

Factor analysis in this study revealed that apart from a weak link to tympanic rim thickness (positive association) and indent (negative association), the orientation of the tympanic anterior side in modern humans is not closely related to any other cranial feature considered. The pattern of variation of this feature within and between modern humans, *H.erectus* and apes noted here is most probably a response to a complex of characteristics. Whether or not a coronally inclined tympanic anterior side can be regarded as a shared-derived trait for Asian and African *H.erectus*, the pattern observed here sheds no light on the likely pathway of modern human origins.

Fig.8.3.10 Tympanic (anterior side) Sagittal Angle

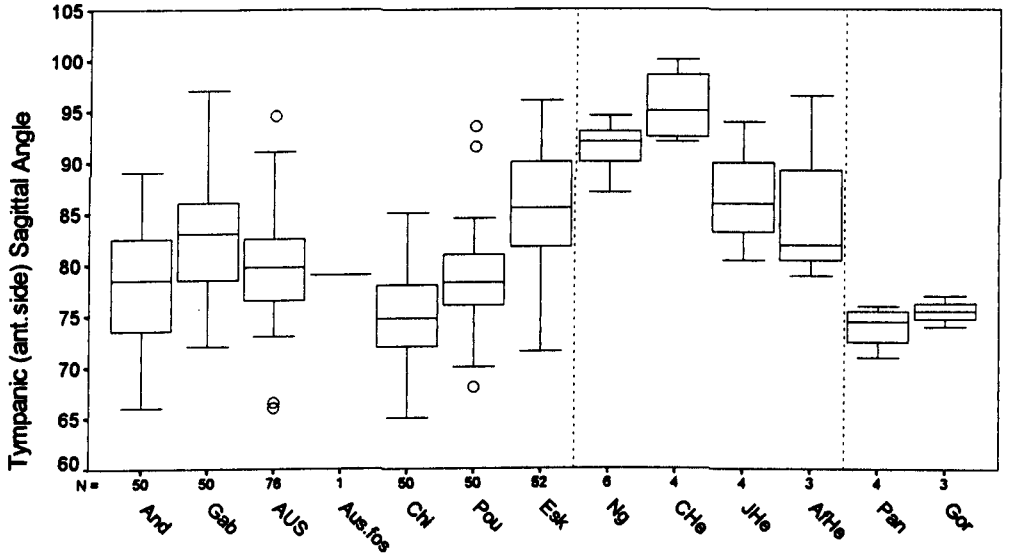


Fig.8.3.11.1 Petrous Axis Sagittal Angle

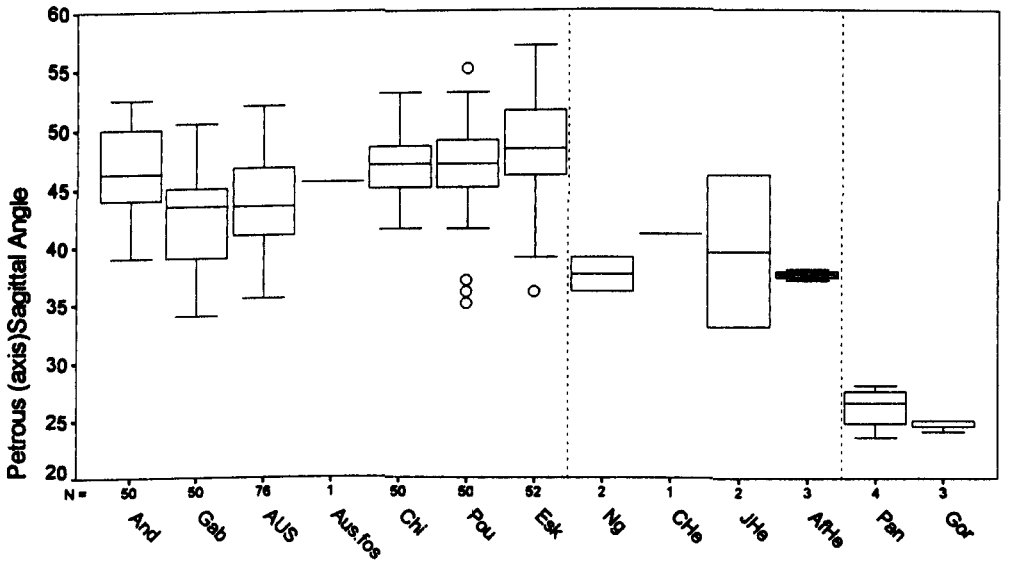


Fig.8.3.11.2 Petrous Sagittal Angle vs.Cranial Base Flexion

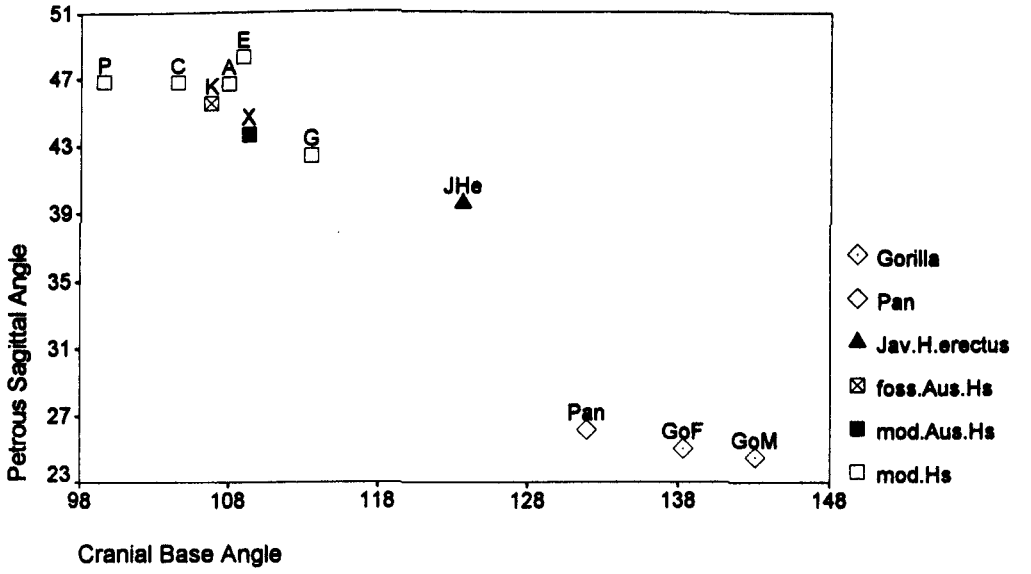


Fig.8.3.11.3 Petrous Sagittal Angle vs.Cranial Breadth/Length Ratio

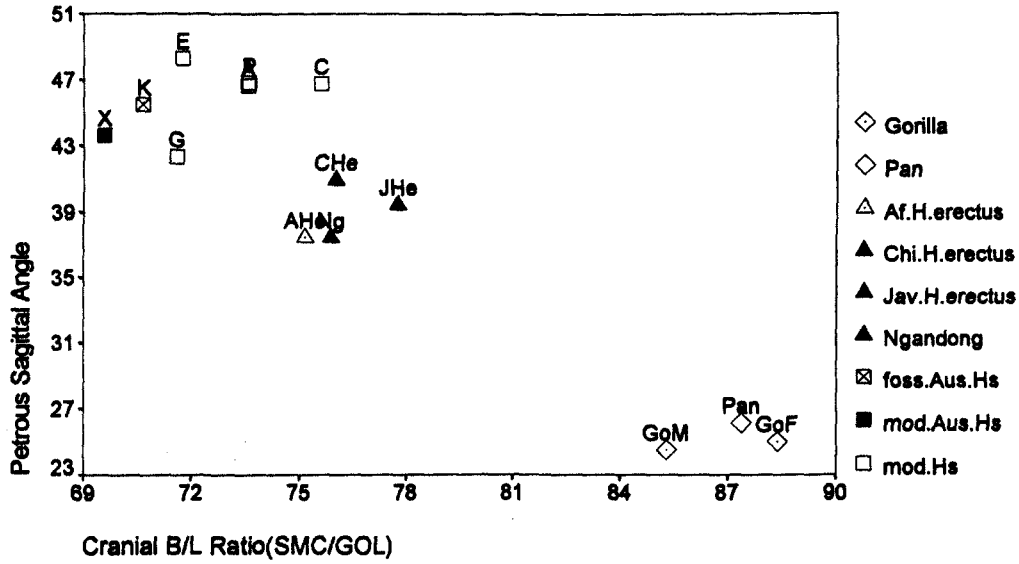


Fig.8.3.11.4 Petrous Sagittal Angle vs.Petrous Length

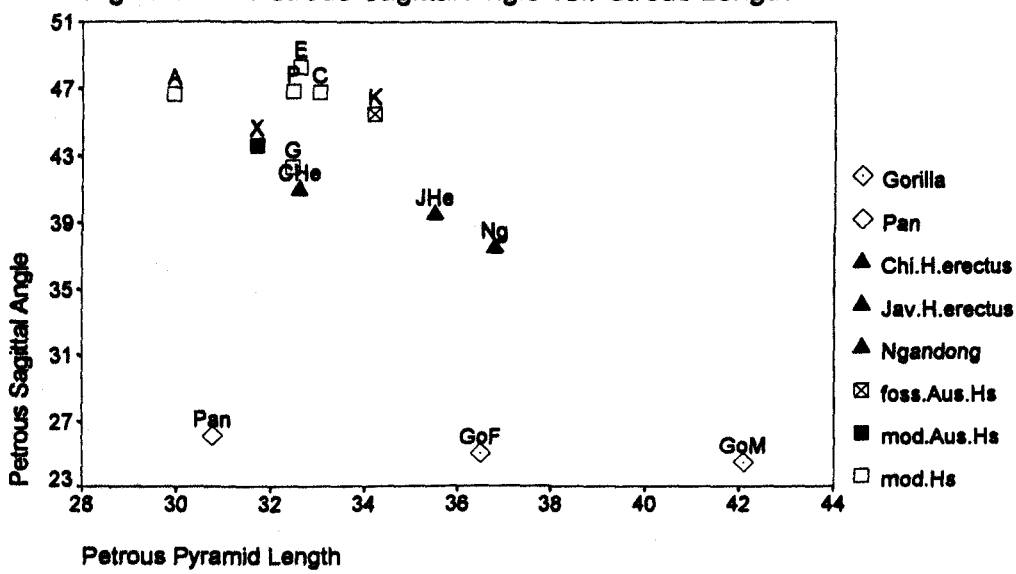
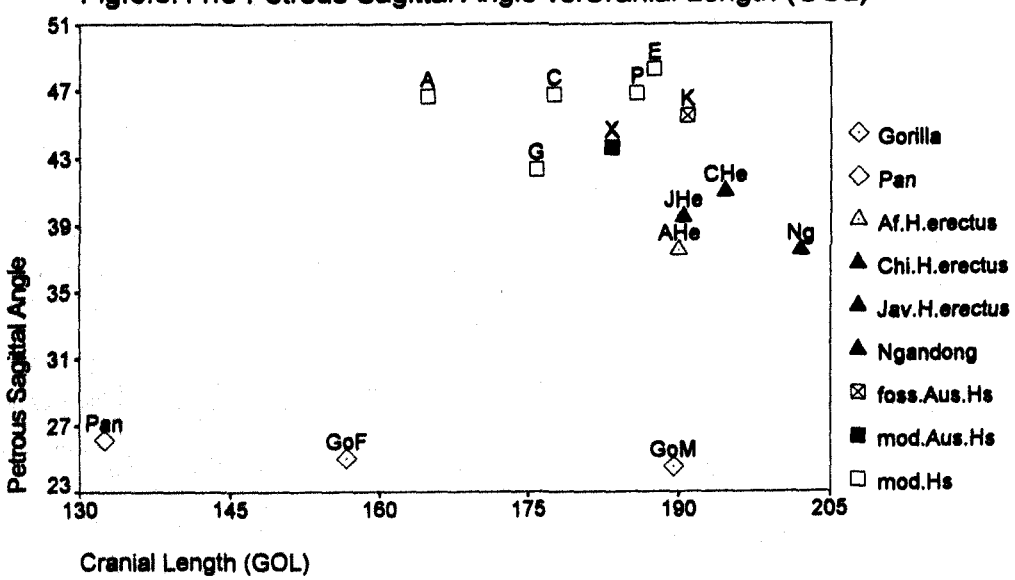


Fig.8.3.11.5 Petrous Sagittal Angle vs.Cranial Length (GOL)



Such a pattern suggests a gradual increase or decrease in the feature from apes to *H.erectus* to modern humans in the course of evolution, rather than its expression in *H.erectus* being a uniquely derived or shared-derived character state.

8.2.3.11 PETROUS AXIS SAGITTAL ANGLE (Fig.8.3.11.1-6). The primitive polarity in this feature is a sagitally inclined petrous pyramid axis; from apes to *H.erectus* to modern humans, the petrous pyramid becomes more coronally inclined. The combined *H.erectus* group mean is significantly greater than *Pan* and *Gorilla* means, and less than all modern human group means, significantly so in relation to all except Gabon and Australian means. Gabon is as similar to *H.erectus* in this feature as to any other modern human group and the Gabon mean is significantly smaller than those of the other modern human groups except Australians. The only modern group which differs significantly from the Australian group is the Eskimo, the group most dissimilar to *H.erectus* and the primitive condition. The Chinese mean is intermediate in the modern range.

The increased coronal orientation of the petrous from apes to *H.erectus* to modern humans has been said to be associated with shortening and broadening of the basicranium, shortening of the tympanic and forward placement of the foramen magnum (Dean & Wood 1981:66,70, 1982:157,168). Luboga likened the effect of the forward displacement of the foramen magnum to a wedge being driven between the left and right petrous-tympanic from behind (Luboga 1986:164). However, as noted for petrous-tympanic angle in section 8.2.3.6, although the petrous becomes more coronally inclined from apes to modern humans as the foramen magnum becomes more anteriorly positioned, *H.erectus* does not follow the trend, having the foramen magnum positioned at least as anterior relative to the bitympanic line as modern humans.

Since a moderately strong positive correlation exists between petrous angle and petrous-tympanic angle, not surprisingly a number of petrous-tympanic angle associations discussed in Section 8.2.3.6 above apply also to the petrous angle and are evident in the bivariate plots of the relevant

group means. For example, from apes to *H.erectus* to modern humans petrous sagittal angle increases as cranial base flexion increases (Fig.8.3.11.2) and as cranial length relative to cranial breadth increases (Fig.8.3.11.3). From *H.erectus* to modern humans, the petrous axis becomes more coronally inclined as the petrous pyramid length decreases (Fig.8.3.1.4), as cranial absolute length decreases (Fig.8.3.11.5) and as mastoid transverse depth decreases (Fig.8.3.11.6). The negative association across species between petrous angle and cranial base angle group means is also evident when only modern humans are considered, and is consistent with the weak negative correlation ($p < .01$) which exists between cranial base angle and petrous axis sagittal angle in modern humans (Appendix Table A.5.2).

8.2.3.12 TEMPORAL SQUAMOUS HEIGHT. (Fig.8.3.12) Temporal squamous height mean increases significantly from African apes to *H.erectus*. It increases from *H.erectus* to all modern human groups, significantly so in relation to the 3 groups with the largest cranial size, Eskimo, Chinese and Poundbury. It has been shown in the factor analysis (Section 6.2.2 & Appendix Table A.5.4) that temporal squamous height in modern humans is positively related to cranial size. The 3 modern human (core) groups with smallest cranial size, -- Andamanese, Gabon and Australian, have temporal squamous height means which although larger than those of *H.erectus*, are not significantly so; their temporal squamous height is as similar to *H.erectus* as to most other modern groups. The primitive polarity is evidently low temporal squamous height.

8.2.3.13 UPPER/LOWER CRANIAL BREADTH RATIO. The polarity of this feature is clearly depicted in Fig.8.3.13, the primitive condition being crania much broader towards the base than across the parietals. From apes to *H.erectus* to modern humans the maximum parietal breadth increases in relation to the lower maximum cranial breadth at the supramastoid crest level. *Pan* and *Gorilla* ratio means are significantly greater than the combined *H.erectus* mean, which is significantly greater than that of any modern group.

The breadth ratios of Eskimos, then Australians are closest of the modern humans to the *H.erectus* condition. The

Fig.8.3.11.6 Petrous Sagittal Angle vs. Mastoid Process Depth

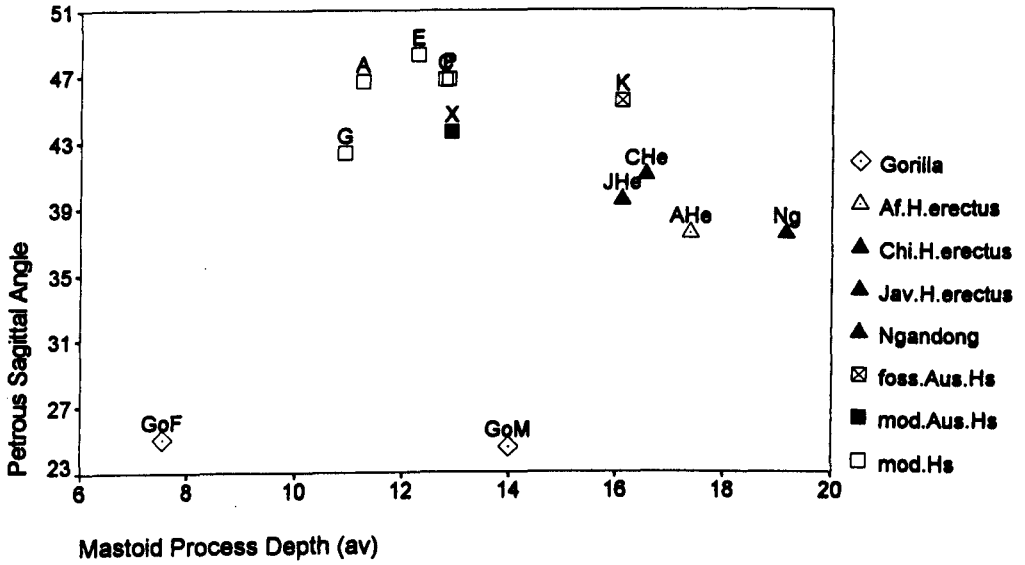


Fig.8.3.12 Temporal Squamous Height

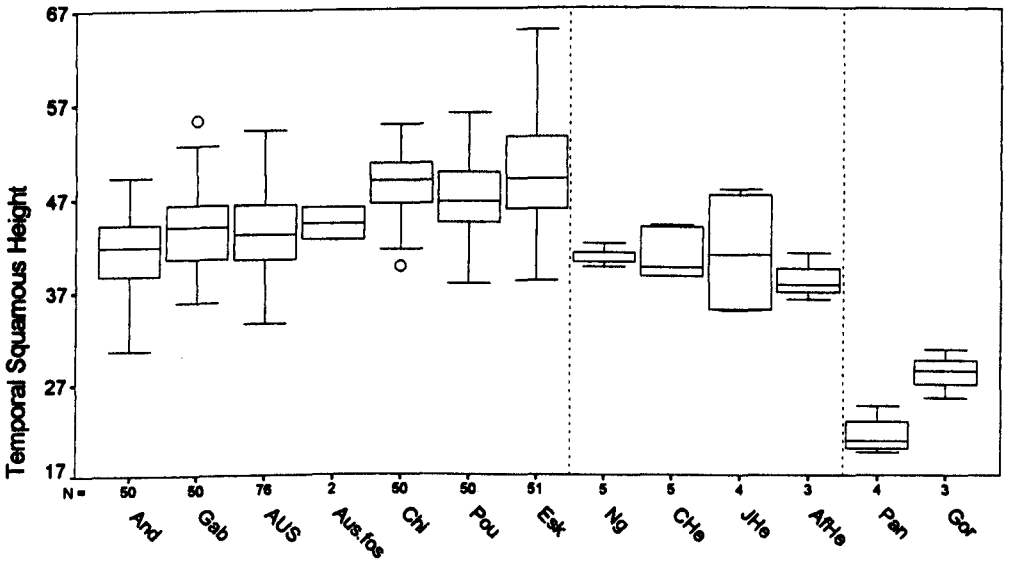


Fig.8.3.13 Lower to Upper Cranial Breadth Ratio

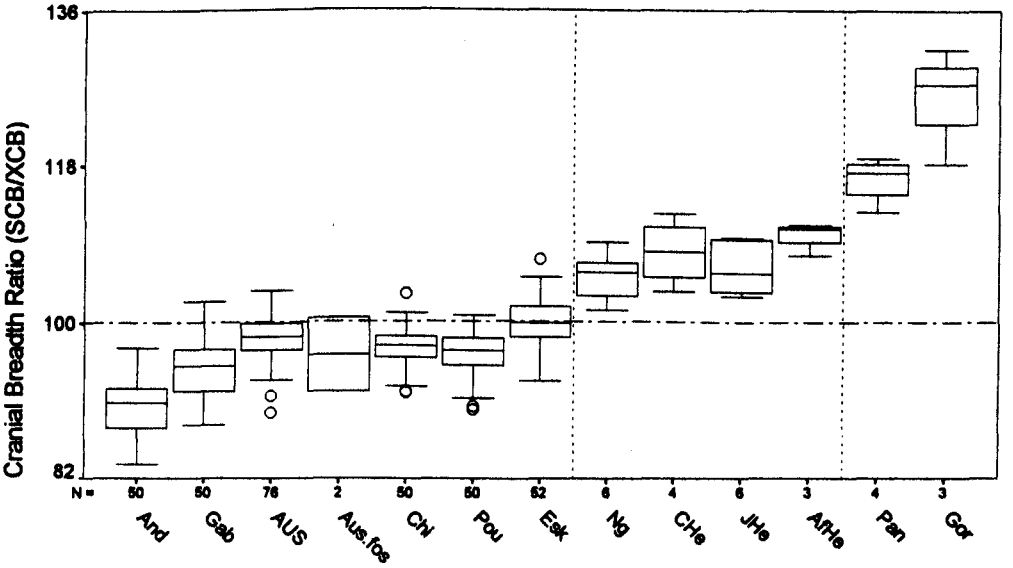
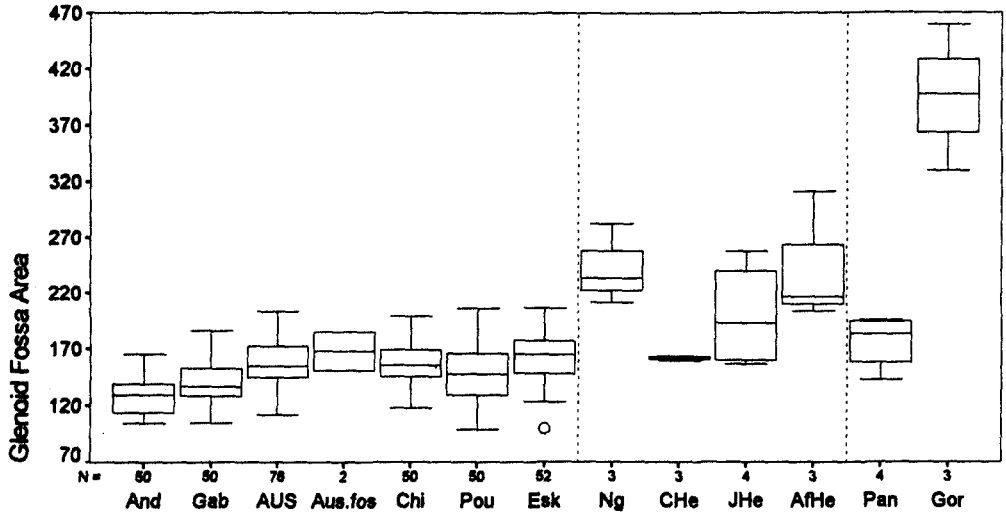


Fig.8.3.14 Glenoid Fossa Area



GFA = {sqrt[(A+B+C)*(A+B-C)*(A-B+C)*(B+C-A)/16]}

Fig.8.3.15 Endinion-Inion Separation

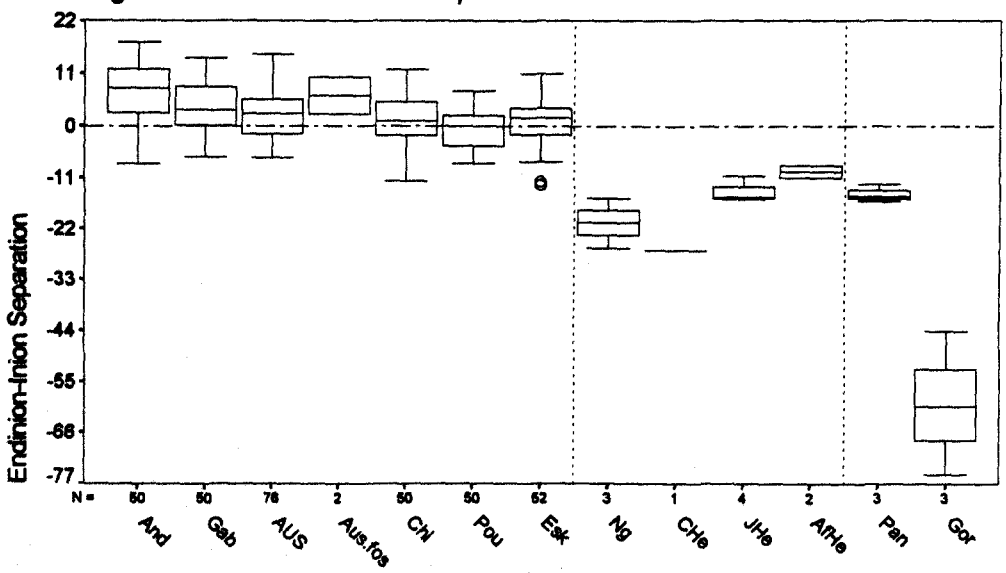
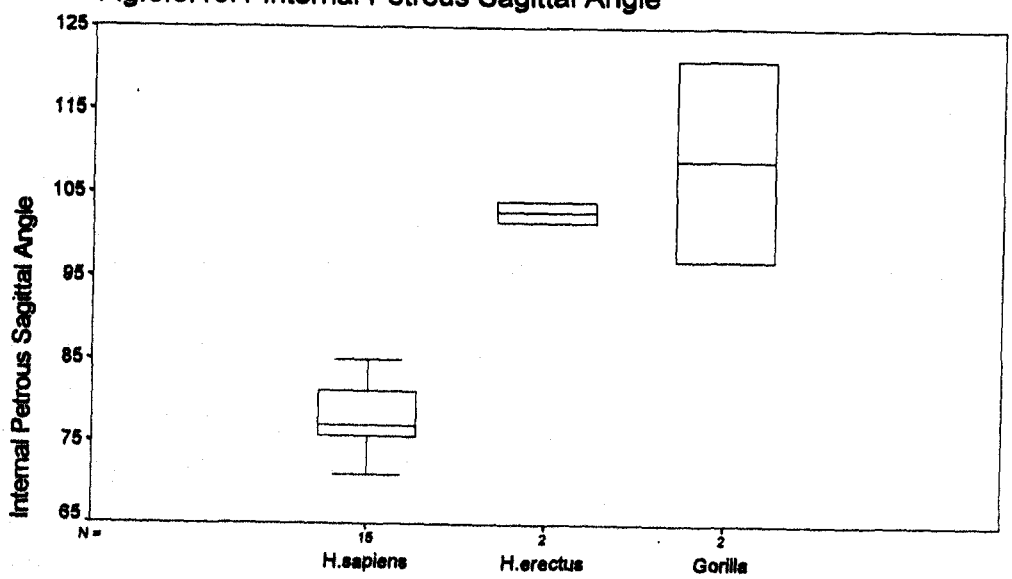


Fig.8.3.16.1 Internal Petrous Sagittal Angle



Eskimo mean is significantly larger than those of all other modern groups except Australians. The Chinese mean is intermediate among the moderns, and the Andamanese mean, consistent with the uniquely prominent bosses of Andamanese crania, is significantly lower than any other group. As has been found in factor analysis, for modern humans there is some positive correlation between overall cranial size and lower/upper cranial breadth ratio; relative to cranial size Australians have a low maximum cranial breadth compared to other modern groups. The upper/lower breadth ratios of nearly all modern crania and all modern group means except that of Eskimos are < 100; i.e. the crania are wider across the parietals than at the supramastoid crest level. All *H.erectus* and apes have ratios > 100, since all have crania with maximum breadth close to the base.

8.2.3.14 GLENOID FOSSA AREA (Fig.8.3.14) The Glenoid fossa decreases in area from Gorilla to *H.erectus* to modern humans. The Gorilla mean is significantly larger than that of all other groups. The combined *H.erectus* glenoid fossa area mean is significantly greater than any modern human group. Eskimos, and recent and fossil Australian groups are the modern groups with means closest to the combined *H.erectus* mean. The range of *Pan* variation is within the total modern human range though the *Pan* mean is larger than that of any modern human group.

It has been established earlier in the study that within modern humans, glenoid fossa area increases with increasing cranial size. This may also be the case in non-modern groups but sample sizes are too small to pursue the possibility here. Across species boundaries, cranial size difference is not adequate to account for the large difference in glenoid fossa area e.g. between modern human groups and *H.erectus*. The decrease in glenoid fossa area from *Gorilla* to *H.erectus* to modern humans may best be explained in relation to decreasing mandible and dental size and function.

8.2.3.15 ENDINION-INION SEPARATION (Fig.8.3.15) In the course of evolution there appears to have been an upward movement of the position of endinion in relation to inion from *Gorilla* to *H.erectus* to modern humans. The primitive condition

is inion located well above endinion. All *H.erectus* and ape crania have endinion located lower than inion. Most modern humans have endinion located slightly higher than inion. The separation in *Gorilla* is significantly greater than in *Pan or H.erectus*. In *H.erectus* and *Pan*, inion is placed higher relative to endinion than in any modern human group; the combined *H.erectus* mean is significantly smaller than any modern human group mean. African *H.erectus* is more similar to all moderns than is Asian *H.erectus*.

Poundbury and Eskimos are the modern groups most similar to *H.erectus* in this feature, but both are considerably closer to other moderns than to *H.erectus*. Andamanese, with greatest separation of endinion above inion is the modern group most dissimilar to *H.erectus*; among the modern humans, Australians are intermediate in this feature.

8.2.3.16 PETROUS TRANSVERSE ANGLE (ENDOCRANIAL). Since it was possible to measure this feature on bisected crania only, sample size is very small. Sangiran 4 and OH9 are the only representatives of *H.erectus*, one *Pan* and a female *Gorilla* comprise the ape sample, and the modern human sample consists of 15 crania of mixed origin (7 regions). It was not possible, therefore, to compare the variation of different modern human or *H.erectus* groups for this feature. However, the analysis did show that the modern human crania sample mean for internal petrous transverse angle is significantly less than the means of either *H.erectus* or *Gorilla*, and there is no significant difference between *H.erectus* and *Gorilla* means (Fig.8.3.16.1). This reflects the more gradually sloping posterior petrous wall in *H.erectus* and *Gorilla* compared to the more vertical structure in modern humans. In these samples, the internal petrous transverse angles are less than 90° in all modern human crania and greater than 90° in all *H.erectus* or *Gorilla* crania, but the situation may not be as distinct with larger samples.

According to Weidenreich, the change in the endocranial posterior surface of the petrous from apes and *H.erectus* to modern humans is a result of the shortening of the cranial base and forward migration of the foramen magnum (Weidenreich, 1943:67,206). When internal petrous transverse angle is plotted against anterior position of basion, there is

Fig.8.3.16.2 Internal Petrous Transverse Angle vs. Anteriority of Basion

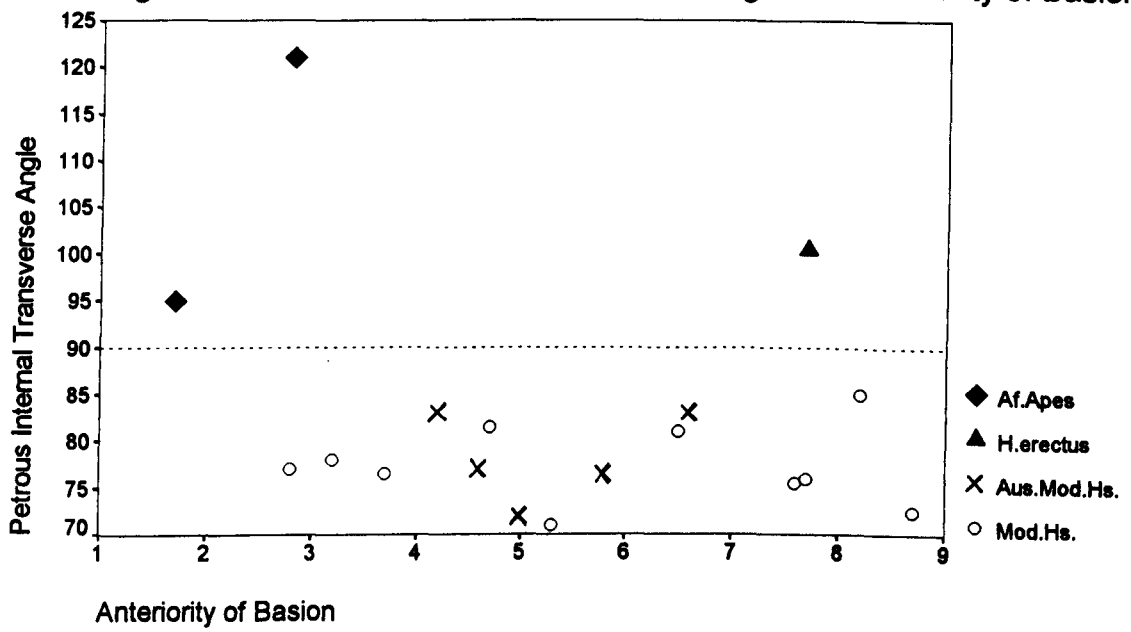


Fig.8.3.16.3 Internal Petrous Transv. Angle vs. F.Magnum Posteriority

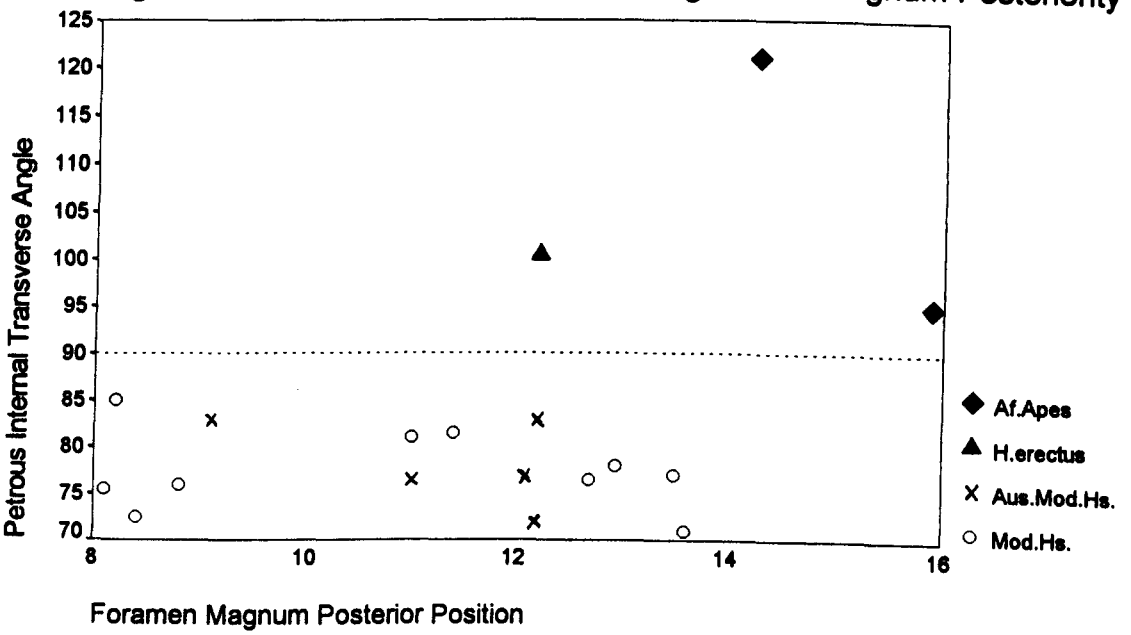


Fig.8.3.16.4 Internal Petrous Transv. Angle vs. Base Angle

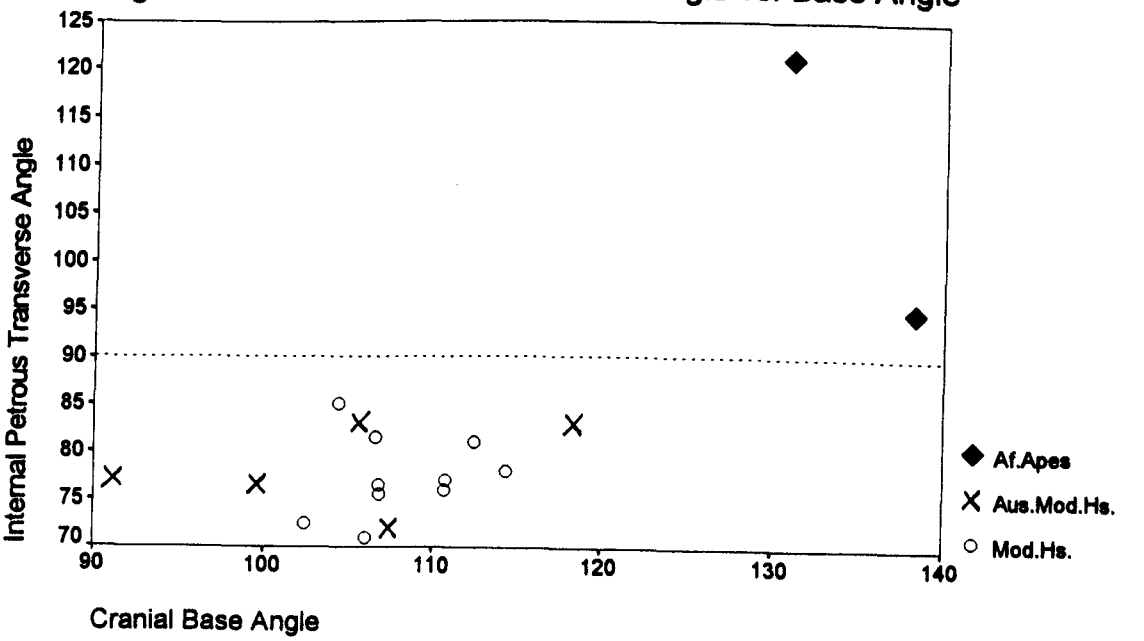
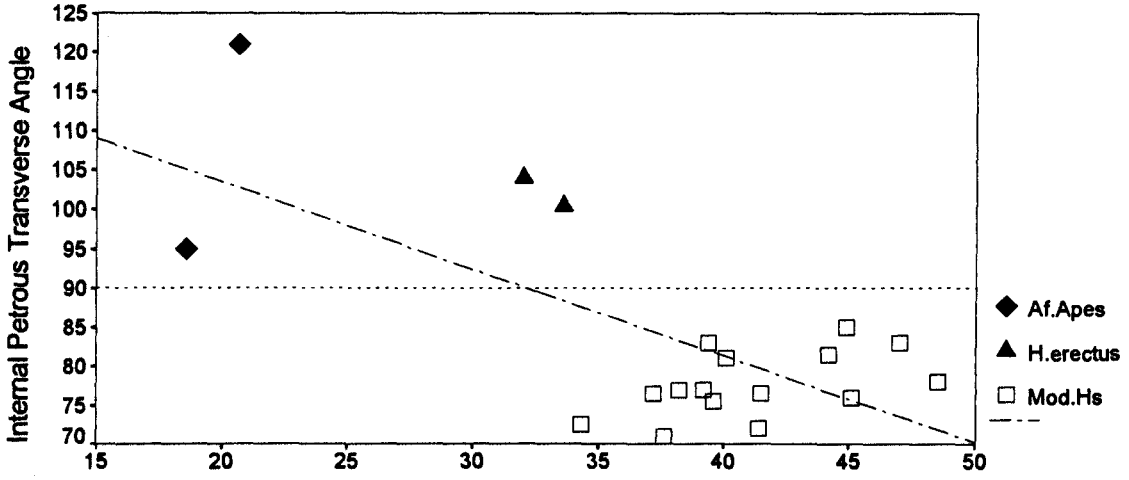


Fig.8.3.16.5 Internal Petrous Transv.Angle vs. Endinion-Opisthion Chor



Endinion-Opisthion Chord

As endinion-opisthion chord (& post. cranial fossa)shorten from apes to H.erectus to mod.humans, the petrous post.surface becomes more vertical.

Fig.8.3.17 Glenoid Fossa Depth

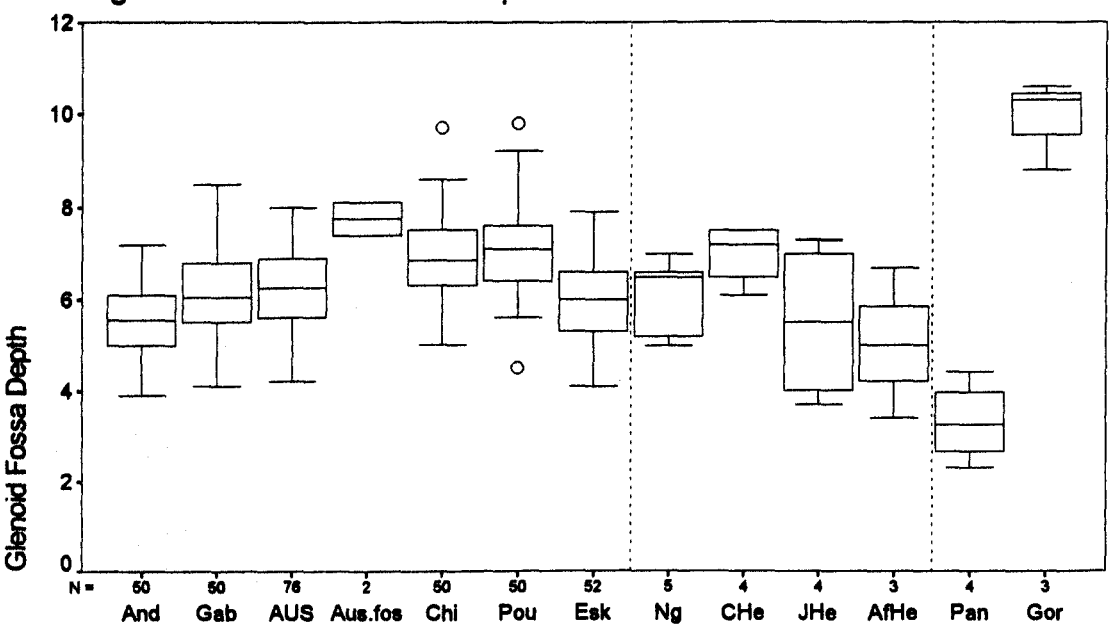
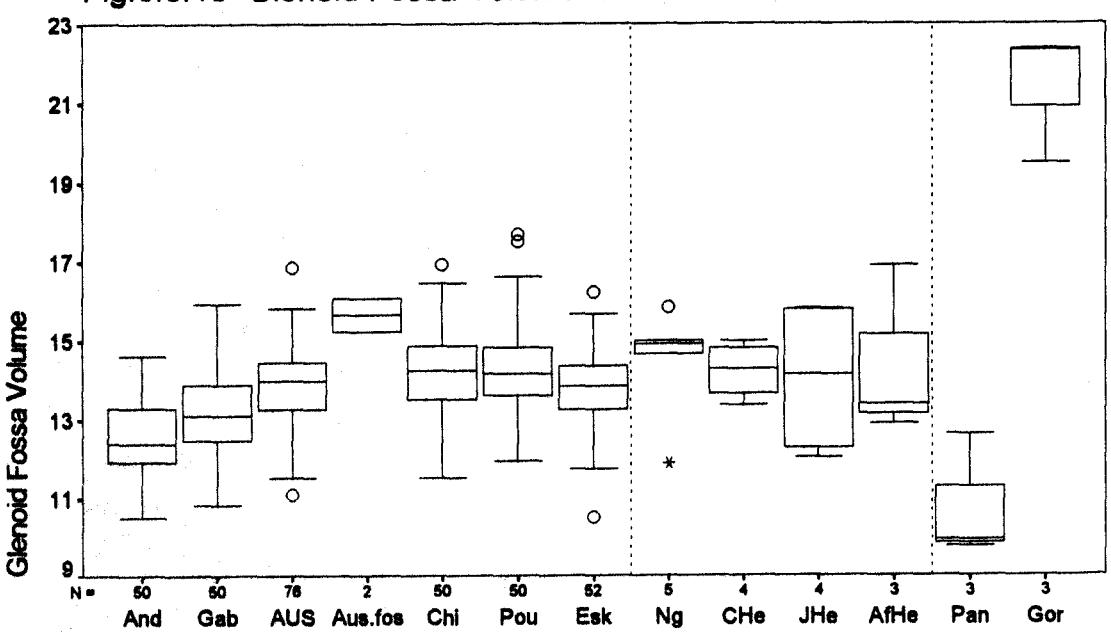


Fig.8.3.18 Glenoid Fossa Volume



indication of a weak negative relationship of the petrous angle with the anterior migration of basion from apes to modern humans. However, the only *H.erectus* representative with data available for both traits has a basion situated well forward compared to modern crania (Fig.8.3.16.2). Similarly, when internal petrous transverse angle is plotted against the posterior location of the centre of the foramen magnum (Fig.8.3.16.3), there is evidence in support of Weidenreich's view that from modern humans to *H.erectus* to apes, as the foramen magnum is situated more posteriorly, the posterior wall of the petrous pyramid slopes more gradually to the floor of the cranium. Within the modern human sample, however, no relationship between internal petrous angle and foramen magnum position is evident.

Cranial base angle could not be measured on either of the 2 *H.erectus* crania providing the internal petrous angle data. But the relationship depicted in Fig.8.3.16.4 between internal petrous transverse angle and cranial base flexion is consistent with increased cranial base flexion from apes to modern humans corresponding to an increasingly acute internal petrous transverse angle and hence, steep posterior petrous wall. Within the modern human sample, however, no such relationship is evident.

There is also indication of a negative relationship between internal petrous transverse angle and endinion-opisthion chord (Fig.18.3.16.5). As the distance between opisthion and endinion increases,(and hence as the posterior cranial fossa lengthens) the internal petrous transverse angle becomes more acute, suggesting a possible link with expansion of the cerebellum. This supports the proposal of Dean (1988:108) that the vertical inclination of the posterior endocranial petrous surface and sharp petrosal crest in modern humans is a result of encroachment of the brain on the petrous temporal bone because of occipital expansion in a short basioccipital. The longer basioccipital in *H.erectus* and apes means there is less compression of the petrous as the occipital expands, and hence the posterior petrous surface is more gradually sloping than in modern humans.

8.2.3.17 & 18 FEATURES IN WHICH *H.ERECTUS* IS VERY SIMILAR TO MODERN HUMANS. Insufficient differences exist between *H.erectus* and modern groups to indicate probable affinities.

8.2.3.17 GLENOID FOSSA DEPTH.(Fig.8.3.17) The *Gorilla* mean for glenoid fossa depth is significantly greater, and *Pan* mean is significantly less than all other group means. There is considerable overlap of *H.erectus* and modern human variation ranges. African and the older Javan *H.erectus* group means are smaller than all modern human means, but not significantly so. Chinese *H.erectus* and Ngandong means are in the midst of the modern human means. The recent Australian mean is intermediate whereas the 2 fossil Australian values, lying at the extreme high end of the Australian range, if considered as a separate group have the largest mean of all groups; but it is to be remembered their "group" consists of only 2 cases.

For modern humans, glenoid fossa depth is a function of cranial size; Eskimos are a notable exception, having a particularly shallow glenoid fossa relative to cranial size. The same positive association between the 2 characteristics does not appear to apply to *H.erectus* groups.

8.2.3.18 GLENOID FOSSA VOLUME (Fig.8.3.18). The *Gorilla* mean for glenoid fossa volume is significantly greater and *Pan* mean is significantly less than all other group means. *H.erectus* and modern humans do not differ significantly in glenoid fossa volume, all *H.erectus* variation ranges lie within the total human range of variation, and there is considerable overlap between *H.erectus* and modern distribution ranges. Apart from Eskimos who have a small glenoid fossa volume for their cranial size, within modern humans, the glenoid fossa volume increases as cranial size increases; the same association appears to apply to *H.erectus* groups and to *Pan* and *Gorilla*.

8.2.4

SUMMARY: DESCRIPTIVE AND QUANTITATIVE FEATURES

Comparison of the variation of 6 descriptive and 18 quantitative features in African and Asian *H.erectus*, African apes, and 6 regionally distinct modern human groups yielded the following findings:

8.2.4.1 DESCRIPTIVE FEATURES

a) The mastoid fissure as defined in this study was found to be present in modern humans (30% having a fissure > 1mm.), present in *Gorilla*, not assessable in *Pan*, present in Asian *H.erectus*, and absent on the only African *H.erectus* assessable in this study. Others have observed it present in African *H.erectus* and other hominids, earlier and later than *H.erectus* (Brauer & Mbua 1992:100). Presence of a mastoid fissure cannot be accepted as an autapomorph of Asian *H.erectus* or as a synapomorph of African and Asian *H.erectus*.

Whether or not the presence of a mastoid fissure is regarded as a useful descriptive feature of Asian *H.erectus*, or *H.erectus* in general, Australians and Chinese are not among the modern groups in which the feature is most common. Among modern humans, a mastoid fissure >1mm. occurs least frequently in the crania of Poundbury and Australians (6.2% and 10.0% respectively), and most frequently in Eskimo and Gabon (51.2% and 54.0% respectively). Chinese show intermediate frequency of occurrence.

There is some evidence of a negative association between mastoid fissure presence and cranial base flexion.

b) A medial recess between the entoglenoid pyramid and the tympanic plate as defined in this study was found to be absent in African apes, present in both African and Asian *H.erectus* and present in modern humans (7.7% with a recess >1mm., 20.9% with a recess >.5mm.). Brauer & Mbua observed substantial medial recesses in other hominids, earlier and later than *H.erectus* (Brauer & Mbua 1992:102,103). On this evidence, presence of a medial recess cannot be accepted as a uniquely derived feature of Asian *H.erectus* or as a shared-derived feature of African and Asian *H.erectus*.

Whether or not the presence of a medial recess is regarded as a useful descriptive feature of Asian *H.erectus*,

or *H.erectus* in general, Australians are least likely of all modern human groups considered to have a recess present (completely absent in 79%; >.5mm.in 4.9%; >1mm.in 2%;). Among modern humans the recess is most evident in Chinese and Eskimo crania. e.g. for Chinese the recess is completely absent in 28%, >.5mm.in 29.5% and >1mm. in 11.4%.

Associated with medial recess occurrence is the presence or absence of a sphenoid spine. It was found to be absent in apes and all *H.erectus* with the questionable exception of Sangiran 17 and Ngandong 7 and 12. A sphenoid spine is common in the modern human sample (> 5mm.in 54.3%; completely absent in only 5.6%). In contrast to the *H.erectus* condition, the sphenoid spine is present in all Australian crania; Andamanese and Gabon are the groups most resembling *H.erectus* in that they have the shortest spine and highest % absent. There is some correlation between length of spine and cranial size; Chinese, Eskimo and Poundbury have the highest % of spines >5mm., while Australians are intermediate in this aspect.

c) A convex medial tympanic region is the condition observed in 14 out of 15 African and Asian *H.erectus* cranial casts as well as African apes. The feature is therefore unlikely as uniquely derived for Asian *H.erectus*, or as a shared-derived feature of African and Asian *H.erectus*. Although the convex and straight conditions do occur in modern humans, a concave medial region is the usual condition (77% concave, 14% convex). Andamanese are an exception in that the convex condition occurs in 64.3% of their crania. Chinese, Poundbury and Eskimo crania are most dissimilar of modern humans to *H.erectus* in that a concave medial tympanic region occurs in 94.3%-98.5% of their crania. Australians are intermediate in the modern variation but < 10% of Australian crania show the convex condition.

A weak negative association of medial tympanic convexity with both tympanic height and cranial size was detected in modern humans; the higher the tympanic plate and the larger the cranium, the more likely the medial tympanic region will be concave.

d) Though the presence of a robust supratubalis has been claimed as a characteristic feature of *H.erectus*, it proved

difficult to observe the feature in *H.erectus* from casts or to assess its form and occurrence in *H.erectus* from descriptions in the literature. Though a satisfactorily comparison of the feature in apes and modern humans with that in *H.erectus* is therefore not possible in this study, yet the condition was assessed for modern humans and apes.

In apes the supratubalis is an extremely long, robust and pointed structure marking the medial termination of the anterior side of the tympanic plate. A similar structure is identified in 47.8% of the modern human sample but in a much shorter and finer form; e.g only 2.9% have a process as long as 5mm. It is present most frequently in Australian crania (67.3%), and absent particularly frequently in Chinese crania (present in 17%). Of the modern human groups considered, the Australian expression of this feature represents the primitive polarity of the feature for modern humans.

Rightmire recognised the supratubalis as present as a similar structure in African and Asian *H.erectus* (Rightmire, 1991:189). If so, it is not autapomorphic for Asian *H.erectus*. Neither is the supratubalis a shared-derived trait for Asian and African *H.erectus* unless it differs significantly from the structures seen in apes or modern humans. The Australians may be regarded as most similar, and Chinese as least similar to *H.erectus* in this feature if the occurrence and size of a comparable supratubalis process in *H.erectus* is found to be between that of modern humans and apes.

e) Insufficient information was available concerning the foramen of Huschke and tegmen tympani in *H.erectus* material for comparison of the pattern of occurrence of the 2 features in *H.erectus* with that in apes and modern humans. Nevertheless, the pattern of variation of the features was assessed for modern humans and apes.

The <u>foramen of Huschke</u> was found to be present in one fifth of modern human crania. It occurs least frequently in Australian and Poundbury crania (7% and 11.2% respectively), and marginally most frequently in Andamanese (30.5%). The incidence in Chinese crania is intermediate. No foramen of Huschke was observed in *Pan* or *Gorilla*. Even though Eskimos with their singularly thick tympanic rim showed the second highest incidence of foramen of Huschke, there is some

indication that generally the incidence of foramen of Huschke decreases as the tympanic rim thickness increases.

No tegmen tympani was observed in the ape sample. It is present in 85.4% of the modern human sample and is wider than 1mm. in 46.6%. The pattern of tegmen tympani occurrence varies greatly from one group to another, being widest and present most frequently in Andamanese (100% occurrence, 76.2% >1mm.), and absent most frequently in Gabon (11% occurrence). In Australians and Chinese it occurs with intermediate frequency.

8.2.4.2 QUANTITATIVE FEATURES

The following findings are based on comparison of group means of 6 modern human groups from different geographical regions, 3 Asian and 1 African *H.erectus* groups and 2 African ape groups.

a) In none of the 3 features in which Asian *H.erectus* groups are noticeably different from African *H.erectus*, are Australians the most similar modern group to Asian *H.erectus*. In 2 of the features, thick tympanic rim and glenoid fossa which is long relative to width, Eskimos and Australians are the most similar modern human groups to the Asian *H.erectus* condition. However, in both features according to group means, Australians are as close or closer to other modern humans than to any Asian *H.erectus* group, while Eskimos are closer to Asian *H.erectus* than to any modern group. Also, there is considerable overlap of variation ranges of *H.erectus* and modern human groups. Thickness in the tympanic rim corresponds to a low maximum cranial breadth and possibly to increased pneumatization of the temporal bone. The tympanic rim of African *H.erectus* is thin in relation to its cranial breadth proportions. At least in modern humans, tympanic rim thickness is likely to be a hereditary character.

Chinese are the modern humans most similar to Asian *H.erectus* in having a deeply indented external auditory meatus. But the Chinese mean is as close or closer to other modern means as to that of Asian *H.erectus* groups. Also, Asian *H.erectus* and modern Chinese crania appear to differ as to the most likely reason for deep indentation of the external acoustic meatus; a prominent suprameatal crest, so extreme in Asian *H.erectus* and contributory to the wide "overhang", is not characteristic of Chinese crania.

b) Of the (4) features in which Ngandong is noticeably different from the other *H.erectus* groups, Australians resemble Ngandong more closely than do other modern humans in one feature, an acute angle between the petrous and tympanic axes. The Australian mean is closer to the Ngandong mean than to 3 of the other 5 modern group means. This may be evidence of Javan-Australian regional continuity or it may simply indicate that the expression of this feature in Ngandong, being intermediate between that of other *H.erectus* groups and modern humans, is typical of late *H.erectus* generally and is furthest of the *H.erectus* groups considered here from the primitive polarity of this feature. This is consistent with all modern humans being closer to Ngandong in this feature than to other *H.erectus* groups. The expression in Australians, the group most similar in the feature to Ngandong, represents the primitive polarity for modern humans. Data on the petrous-tympanic angle of *Homo* contemporaries of Ngandong, from other regions would help resolve the matter.

The petrous-tympanic angle was found to increase from apes to *H.erectus* to modern humans as the cranium becomes more flexed, as the petrous pyramid and tympanic plate shorten and as cranial length relative to cranial breadth increases. The angle also increases from *H.erectus* to modern humans as crania shorten absolutely and mastoid transverse depth decreases. If only modern human groups are considered, some petrous-tympanic angle associations are the same (cranial base flexion, petrous and tympanic length and mastoid transverse depth). No clear relationship is evident across the species between petrous-tympanic angle and foramen magnum anterior-posterior position.

In 2 features, Australians and one other group are more similar to Ngandong condition than are other modern humans: coronally inclined tympanic axis (Eskimos and Australians), and long nuchal plane relative to the upper occipital plane (Poundbury and Australians). According to group means, Australians and Eskimos are similarly close to Ngandong in tympanic axis angle; but Australians are closer to other modern human groups than to Ngandong, whereas Eskimos are closer to Ngandong than to other modern humans. In the occipital/nuchal chord ratio, the Australian mean is not as close as that of Poundbury to the Ngandong mean and the means of both groups are closer to other modern human group means

than to Ngandong.

In both features, the Ngandong mean is intermediate between the other *H.erectus* group means and modern human group means. Therefore, as outlined for petrous-tympanic angle, the modern human group most similar to the Ngandong condition may simply be the group showing the primitive polarity of the feature in modern humans rather than a particular affinity with Ngandong.

The Ngandong mean for suprameatal crest angle is significantly less than that of other *H.erectus* groups, but since the Ngandong distribution is intermediate in the total human range, comparison of its mean with modern group means cannot lead to indications of possible regional continuity. Eskimos, with the most vertically oriented suprameatal crest of all modern humans, show greater similarity to the early *H.erectus* groups in this feature than to other modern groups, and probably reflects the massive mandible dimensions characteristic of Eskimos.

c) In 11 of the features there is no apparent difference between Asian and African *H.erectus* groups, or between Ngandong and other *H.erectus* groups, or between Chinese *H.erectus* and other *H.erectus* groups. Australians are the most similar of modern humans to *H.erectus* in just one of these features, a transversely deep mastoid process. However, the Australian mean is only marginally larger than 2 other modern groups (Poundbury and Chinese) and all recent modern means are significantly less than the mean of combined *H.erectus* groups.

A mastoid process which is particularly deep in the transverse direction may be a shared-derived trait of African and Asian *H.erectus* (A comparison with other hominid groups would be needed to confirm this). Whether or not this is the case, no inferences about regional continuity can be drawn from the pattern of mastoid depth variance.

In 5 other such features, Australians and 1 other group are more similar than other modern human groups to the general *H.erectus* condition:

sharply angled occipital (Poundbury and Australian).
large glenoid fossa area (Eskimo and Australian);
large lower/upper cranial breadth (Eskimo and Australian);
sagitally inclined petrous angle (Gabon and Australian);

low temporal squamous (Andamanese and Australian);
For each of the features there is one other modern group which is closer to the *H.erectus* condition than Australians.

Although Poundbury and Australian crania have the most sharply curved occipitals of modern humans, they are more similar in this feature to other modern humans than to the *H.erectus* condition; all modern human means for this feature are significantly smaller than *H.erectus* means. The extremely sharp angled occipital of all *H.erectus* is associated with the characteristically prominent occipital tori of *H.erectus* crania. As in the case of mastoid depth, this may be a shared-derived feature for African and Asian *H.erectus*, but whether or not it is, no inferences concerning regional continuity can be made from the pattern of variance.

In the remaining 4 features, the *H.erectus* condition is intermediate between apes and modern humans, and the modern human group most similar to *H.erectus* in a particular feature is merely showing the primitive polarity for the modern distribution. Except for sagittal petrous angle, there is a moderately strong association of these traits with cranial size, at least for modern humans.

d) Since internal petrous transverse angle could be measured on only a few crania, it was not possible to compare the variation for individual modern human or *H.erectus* groups. But it was found that the internal petrous transverse angle is significantly more acute and the internal petrous wall steeper in modern humans than in *H.erectus* and *Gorilla*. Indication of a weak positive correlation of internal petrous transverse angle with posterior location of the foramen magnum is consistent with Weidenreich's view that from apes to modern humans the forward migration of the foramen magnum is associated with the petrous pyramid internal surface becoming taller and sagitally shorter, and the posterior wall becoming steeper. A negative correlation of the internal petrous transverse angle with endinion-inion separation suggests a link with expansion of the cerebellar fossa.

8.2.5 CONCLUSION

The pattern of variation of the features examined in African ape, *H.erectus* and modern human groups produced no clear evidence of continuity between modern Australians and Asian *H.erectus* or Ngandong, or between modern Chinese and Asian or Chinese *H.erectus*. At the same time, no evidence emerged of any features which could be said to be autapomorphic for Asian *H.erectus* and which would thereby exclude Asian *H.erectus* as a possible modern human ancestor.

CHAPTER 9

FINAL DISCUSSION AND CONCLUSIONS

9.1. ASPECTS OF THE TEMPORAL BONE COMMON TO MODERN HUMANS

9.1.1. ASSOCIATION OF TEMPORAL VARIABLES WITH OTHER VARIABLES. The following associations of temporal variables with each other or with non-temporal variables were found to apply to the whole modern human sample of 443 crania representing 11 populations.

9.1.1.1. SIZE DEPENDENCE. Non-linear temporal variables are independent of overall cranial size dimensions. Although linear temporal variables show weak to moderate dependence on cranial size, factor analysis indicated that 75% of the variance in temporal features is related to factors other than cranial size. Size-adjustment of temporal variables does not improve discrimination. Except for petrous length and temporal squamous height, linear temporal variables are more closely related to cranial breadth than to cranial length or height.

9.1.1.2. PETROUS AND TYMPANIC AXES ORIENTATION. By definition the petrous-tympanic angle increases as the petrous axis becomes less sagitally inclined and the tympanic axis becomes more sagitally inclined, but petrous and tympanic axes show some mutual independence.

The tympanic axis tends to be more sagitally inclined the more anteriorly positioned the foramen magnum, a trend consistent with correspondence between the increasing petrous-tympanic angle and the forward migration of the foramen magnum from apes to modern humans (Aiello & Dean 1990:69-71, Dean & Wood 1981:168; Luboga 1986:164).

The petrous axis shows some tendency to become less sagitally inclined as nasal aperture narrows. (Nasal aperture is otherwise independent of all temporal and non-temporal variables considered in this study).

9.1.1.3. TYMPANIC PLATE LATERAL RIM. A tympanic plate with thick lateral rim tends to protrude laterally, have a more coronally inclined anterior side and belong to crania

which are long relative to breadth, have a small biparietal breadth and a low maximum cranial breadth.

9.1.1.4. A MASTOID PROCESS AXIS acutely inclined to the Frankfurt horizontal tends to be associated with crania which are long relative to breadth and in which the foramen magnum is rotated forwards.

9.1.1.5. All qualitative temporal variables, with the possible exception of mastoid fissure occurrence, are independent of CRANIAL BASE FLEXION. Mastoid fissure frequency shows a weak tendency to decrease as cranial base flexion increases.

9.1.1.6. All external temporal variables are independent of the occipital variables ENDINION-INION separation, OPISTHOCRANION-INION separation and upper/lower OCCIPITAL CHORD RATIO. These 3 occipital variables appear to be also independent of other cranial variables in general and are most probably related primarily to relative sizes of nuchal musculature, cerebellum and cerebrum.

9.1.2 ASYMMETRY IN BILATERAL TEMPORAL VARIABLES.

9.1.2.1. ASYMMETRIC TEMPORAL VARIABLES: Several bilateral temporal variables show asymmetry in modern humans in general.

(i) Variables with larger values on the RIGHT side: Mastoid depth, length, width, volume; petrous sagittal angle; tympanic anterior sagittal angle; tympanic rim thickness; external auditory meatus angle; glenoid fossa depth; jugular fossa area; petrous-tympanic angle.

(ii) Variables with larger values on the LEFT side: Glenoid fossa area; tympanic plate height and sagittal angle.

9.1.2.2. ASYMMETRY ASSOCIATIONS: POSSIBLE IMPLICATIONS. The asymmetry of the jugular fossa in modern man is recognized in the literature (Gray 1989:359; Hauser et al.1989:133; Krogman 1932:410), though a slightly higher incidence of a larger right fossa was found in this study (74.3%) than the reported finding of 65.4% in a study by Di Chiro, 1964 (in Hauser & De Stefano 1989:133).

From the results of the present study it is proposed that asymmetry in both jugular fossa and sigmoid sulcus size accounts for much of the asymmetry in bilateral temporal variables. Asymmetry in jugular fossa size is closely linked

to that in sigmoid sulcus size because of one important aspect of intracranial blood flow asymmetry. The right sigmoid sinus is larger than the left since the right transverse sinus with which it is continuous receives blood from the large superior sagittal sinus, whereas the left transverse sinus receives blood from the smaller straight sinus (Aiello & Dean 1990:169-172; Frazer 1920:196, Gray 1994:425,426); blood from the sigmoid sinus leaves the cranium via the jugular fossa in the internal jugular vein, the right one of which is reported as usually being larger than the left (Gray 1994:421).

Sigmoid sulcus size directly affects mastoid process size, and the asymmetry of both structures is likely to affect the external auditory meatus orientation, the tympanic anterior orientation and possibly the glenoid fossa size. A larger sigmoid sulcus and mastoid process on the right, together with a thicker right tympanic rim, correspond to a more vertically inclined external auditory meatus, a more coronally inclined tympanic anterior side and a smaller glenoid fossa area on the right side.

The asymmetry of the tympanic rim thickness was noted, but without explanation, by Stewart (1933:488). The larger glenoid fossa area on the left and the greater depth on the right may be spatially compensatory trends to achieve the bilaterally symmetric glenoid fossa volume. The larger jugular fossa on the right is linked to the more coronally inclined petrous, the more sagitally inclined tympanic and hence, the larger petrous-tympanic angle on the right. Consequently, the jugular fossa and sigmoid sulcus asymmetries together appear to link most of the temporal asymmetries into the one complex.

The size of both the jugular fossa and sigmoid sulcus is reported to increase from anthropoids to *H.erectus* to modern humans (Weidenreich 1943:61,206). The connection noted in this study between the asymmetries of jugular fossa, sigmoid sulcus and most asymmetry in temporal features of modern humans indicates that jugular fossa size, sigmoid sulcus size and associated intracranial blood flow contribute at least in part to changes in some temporal bone features from anthropoids to *H.erectus* to modern humans, such as increasing petrous-tympanic angle and more coronally oriented petrous axis (noted in Aiello & Dean 1990:69-71; Dean & Wood 1981:54,1982:168; Weidenreich 1943:204; confirmed this study).

The diagram in Fig.9.1 represents in summary form many of the associations relating to modern human temporal variation and asymmetries which were observed in this study, together with some probable indirect relationships such as the degree of cerebellar development. The real situation is likely to be more complex in that any one temporal feature may be influenced by other factors besides the ones represented, but also simpler in that several features depicted may well be part of the one complex. For instance, one important simplifying connection probably exists between increased cranial breadth to length ratio and increased cranial base flexion.

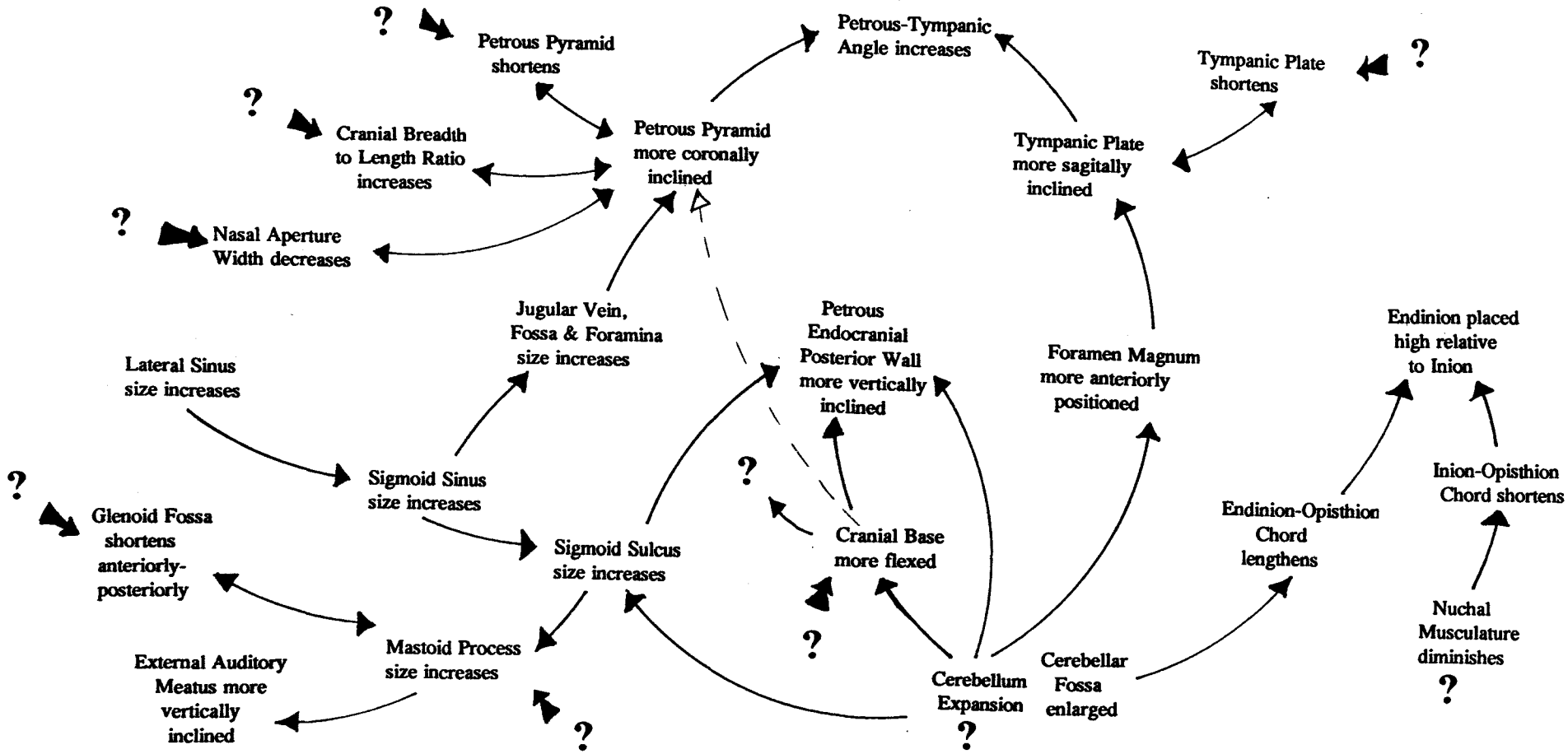


Fig.9.1 INTERRELATIONSHIPS OF SOME MODERN HUMAN CRANIAL FEATURES SUGGESTED BY TEMPORAL VARIATION & ASYMMETRY OBSERVED IN THIS STUDY.

The relationships summarized in the diagram are based on evidence provided in this study. However, any feature depicted is understood to be dependent also on other factors besides the ones represented here.

9.2 TEMPORAL BONE VARIATION BETWEEN MODERN HUMAN GROUPS

9.2.1. CAN TEMPORAL BONE VARIATION DISCRIMINATE MODERN HUMAN POPULATIONS?

Numerous studies have shown that modern human populations can be discriminated from one another to a greater or lesser degree on the basis of cranial features; the traits involved have been various combinations and numbers of overall cranial dimensions, facial, mandibular or dental measurements. This study has demonstrated that modern human populations, represented by 11 population samples, can be discriminated from one another by 17 temporal variables alone.

Even so, the variation in temporal bone morphology between different modern human populations is small compared to the variation within the groups. This was also found to be the case in studies involving more general cranial variables. Such a pattern is not readily reconciled with an ancient origin of regional variation as proposed by the Multiregional hypothesis; rather it supports a recent divergence of modern humans (Howells 1989:83; in press; Relethford 1994:54,60; Stringer & Andrews 1988:1264).

9.2.2 THE MODERN AUSTRALIAN TEMPORAL BONE

9.2.2.1. ARE AUSTRALIANS EXCEPTIONALLY DIFFERENT IN TEMPORAL BONE FEATURES COMPARED TO OTHER MODERN HUMAN GROUPS?

In studies of modern human variation based on general cranial features, Australians were found to be slightly more divergent than other modern human group (Howells 1989:71), or even markedly different (Lahr 1992:280).

Some of the modern human groups considered in this study can be distinguished more readily than other groups by temporal variable discrimination. Australians are among those best discriminated by temporal features, but they do not have the most distinctive temporal region of modern humans. Eskimos and Andamanese are more effectively discriminated on the basis of temporal features than are Australians.

Australians have no temporal bone feature or combination of features in which they differ remarkably from all other modern human groups. Only Eskimos can be regarded as

exceptionally different in temporal bone features to other modern humans, and that on the basis of mainly one variable, tympanic plate lateral rim thickness.

9.2.2.2 TEMPORAL FEATURES WHICH DISTINGUISH AUSTRALIANS.

Although it was found that Australians do not differ significantly in any temporal variable from all other 10 modern humans groups considered or from all other 5 core groups, they differ most in and are most effectively distinguished by an acutely inclined, long and transversely deep mastoid process in combination with a long, wide glenoid fossa and a sagitally inclined petrous pyramid. According to absolute group means, of the 6 core modern human groups the Australians have the deepest mastoid process and the smallest petrous-tympanic angle. Comparing all 11 modern human groups, the mastoid process axis of Australians is the most acutely inclined towards the Frankfurt Horizontal. The main function of the mastoid process is as a surface of attachment for the 3 muscles (sterno-mastoid, splenius capitis and trachelo-mastoid) concerned with different aspects of the balancing, turning and flexion of the head. The orientation of the mastoid process would be governed by the combined effect of the orientation of the 3 muscles, which in turn would depend on such factors as the degree of prognathism, the angle at which the head is held, the length of the neck, and the weight and placement of superstructures such as occipital tori, supraorbital arches. A weak positive correlation was found between the mastoid axis angle and the foramen magnum angle (which gives a measure of the angle at which the head is held). Since many Australian crania exhibit substantial lower face prognathism, it is a possible link with the acute mastoid angle in Australians. However, suitable variables which measure prognathism were not included in this study. Lower face prognathism is regarded as a primitive retained feature (Howells 1989:14; Lahr 1994:38,40,44; Lieberman 1995:172).

9.2.2.3. CHARACTERISTIC AUSTRALIAN TEMPORAL BONE FEATURES.

A MASTOID PROCESS which is long, very deep transversely, somewhat narrow, intermediate in volume and inclined particularly acutely to the Frankfurt Horizontal.

A SUPRAMEATAL CREST which is inclined acutely towards the Frankfurt Horizontal.

A GLENOID FOSSA which is intermediate in depth, volume and

length/width ratio, and which, relative to cranial size is long, wide and large in area.

A low TEMPORAL SQUAMOUS, the lowest relative to cranial size of the 6 core groups.

A PETROUS PYRAMID which is intermediate in length, with an axis which is particularly sagitally inclined and makes a particularly small angle with the tympanic axis.

A TYMPANIC PLATE which is low, quite long and has a very thick, protruding lateral rim.

9.2.3 AFFINITIES OF MODERN HUMAN GROUPS BASED ON TEMPORAL FEATURES

The clustering of modern human groups arrived at on the basis of temporal bone similarities does not necessarily correspond to phylogenetic groupings (Tattersal 1986:166), yet Relethford (1994:53,60) found good agreement between craniometric and genetic variation among modern human groups.

Most but not all of the affinities between modern human populations indicated by temporal similarities, particularly in the grouping of Australians with Africans rather than Asians, correspond closely to the findings from analyses of between-groups variation of more general cranial variables in this study (using 17 non-temporal variables) and in other recent craniometric studies (Howells 1989:83; Lahr 1992:272, 1994:47-49; Lahr & Foley 1994:53; Luboga 1986:340,341; Relethford & Harpending 1994:259-261; Wright 1992:132). The results do not support the findings of similar studies which concluded that Australians are most similar to East Asians, (Neves & Pucciarelli 1991:270; Pope 1992a:3; Wu 1992:373).

Although some temporal variables show a degree of correlation with a number of non-temporal variables, yet factor analysis has shown that temporal variables are largely independent of other cranial variables. Therefore it must be concluded that temporal variables offer additional independent evidence for the existence of the affinities outlined in the following sections 9.2.3.1-9:

9.2.3.1 Overall Pattern of Affinities. Modern human groups can be regarded as divided into 3 main clusters according to similarities in temporal features (non-core groups are in brackets):

a) AFRICAN-AUSTRALIAN: Gabon, Australian, Andamanese, (Bushman, Veddah, New Britain, Tasmanian)

b) ASIAN-EUROPEAN: Chinese, Poundbury, (Fuegian)

c) ESKIMOS:

Except for the clear separation of the Eskimos from all other groups considered in this study, the above pattern of likely affinities according to temporal similarities matches closely that determined by Howells from general cranial shape variables. He found that Africans and Australo-Melanesians constitute a main cluster, well separated from Asian and European groups (Howells 1989:37-39,46). The temporal basis for their separation is the comparatively low temporal squamous, low tympanic plate and narrow mastoid process of the African-Australian groups. If just Africans, Australians, Europeans and East Asians are considered, this pattern of affinities closely matches the divisions obtained by Relethford and Harpending (1994:258-261) using general cranial variables and also by Luboga (1986:340,341) using a combination of facial, basal temporal and general cranial variables.

A similar pattern of affinities is indicated by the non-temporal variables examined in this study, except that Eskimos are not nearly as extreme; Howells found their position somewhat equivocal, closest to Polynesians (not represented in this study) but, as in this study, more similar to E.Asian groups than Africans, Australians or Europeans (Howells 1989:37,39).

9.2.3.2. Australo-Melanesian Affinity. The Australian temporal bone has closest resemblance to that of New Britain and a little less to Tasmanians. This same Australo-Melanesian affinity is indicated by general cranial shape (this study Sections 7.2.4, 7.4.5, Brace & Hunt 1990:343,353; Howells 1976:641, 646-648, 1989:14,63,71; Pietrusewsky 1983:61; 1990:319,333; Wright 1992:133) and dental pattern (Turner 1992a:149). But both Tasmanian and New Britain crania differ most notably from Australians in having a considerably thinner tympanic lateral rim; Tasmanians also differ in having a smaller, more vertically inclined mastoid process and a more coronally oriented petrous pyramid.

9.2.3.3 Australian-East Asian Contrast. Of all modern groups, the Chinese are most dissimilar to Australians in the

temporal bone, and in general cranial shape (this study Sections 7.2.2 & 7.4.3; Howells 1989:37,46). The contrast in temporal features seen in this study further supports the claim that in general cranial shape Australo-Melanesians and East Asians are "the most contrasting populations of modern humanity" (Howells 1989:57). The high temporal squamous and tympanic plate, the thin tympanic lateral rim, the vertically inclined mastoid process and the coronally inclined petrous pyramid of Chinese crania are in sharp contrast to the expression of these temporal bone aspects in Australians. The contrast is also consistent with the difference Turner identified in the specialised dental morphology of Chinese as Sinodonts and the simpler pattern seen in S.E.Asians and Australians (Turner 1992a:149).

9.2.3.4 Australian-African Affinity. Temporal similarities indicate Australo-Melanesians and Africans (Gabon and Bushman) are closer to each other than either is to E.Asian (Chinese) or European (Poundbury). This corresponds to affinities based on general cranial shape (this study, Section 7.4.3; Howells 1989:37-39) and dental similarities (Turner 1992b:422). Australians and Gabon have in common a particularly small petrous-tympanic angle and sagitally inclined petrous pyramid. This result concurs with Lahr's findings (Lahr 1992:91,1994:41).

9.2.3.5 Bushman-Gabon Affinity. The temporal bone of Bushman greatly resembles that of Gabon and thus confirms the strong affinity between Bushman and other African populations suggested by general cranial shape (this study, Section 7.4.3 & 7.4.5; Howells 1989:13,33,37,53). As Howells pointed out, this contradicts the claim by Coon (1962:651) that Bushman evolved as "a phyletic line separate from other Africans" (Howells 1989:13). Bushman differ from Gabon most noticeably in having a thinner tympanic plate lateral rim and more acutely inclined mastoid process.

9.2.3.6 Andamanese-African Affinity. Andamanese show their closest affinity with Gabon on the basis of temporal bone likeness (this study, Section 7.2.4 & 7.4.3; Howells 1989:37,39). A similar pattern is evident using other cranial variables (this study, Section 7.3.2.2).

9.2.3.7 Veddah-African Affinity (Sections 7.3.4 & 7.4.3) Veddah show greater resemblance in temporal features to Gabon

than to any other group and differ from Gabon most noticeably in having a more coronally oriented petrous pyramid. Mongoloid affinity suggested by Morant (1928:3) is not evident in temporal features (or even in the non-temporal features investigated in this study). The temporal features of Veddah and Gabon tend to be the most generalised of all modern humans considered.

9.2.3.8 American-East Asian Affinity. The only 2 American populations represented in this study are Eskimos and Fuegians. In most aspects of the temporal bone, Fuegians are intermediate in similarity between Chinese and the remote Eskimos; both groups are more similar to Chinese than to Africans and (usually) to Australians (This study, Sections 7.2.4 & 7.4.5). The implied affinity of the Fuegians to Chinese on the one hand and Eskimos on the other is not close. The same pattern of a Fuegian link between Chinese and Eskimos was also suggested in this study on the basis of general cranial shape (this study, Section 7.3.2). Howells described Eskimos as specialized Mongoloids, though he found Eskimo affinities equivocal (Howells 1989:14,37-39,45). Eskimos share a Sinodont dental pattern with Chinese (Turner 1992b:422,426). The most noticeable difference between Chinese and Eskimos is in the higher, thinner tympanic plate of the Chinese. The affinity between early Australians and early South Americans detected by Neves an Pucciarelli (1991:270) suggesting to them the possibility of a common East Asian ancestor, is not supported by affinities based on temporal variation.

9.2.3.10 Eskimos are far more strongly separated from other modern human groups on the basis of temporal features than on the basis of general cranial features (this study, Sections 7.3.4 & 7.4.3 & 5. Howells 1989:56,71). This attests to the extreme distinctiveness of the Eskimo temporal bone which clearly separates the Eskimo from all other modern human groups on the basis of an exceptionally thick tympanic lateral rim, a feature even further enhanced by combination with a long (ant./post.) glenoid fossa process. The thick tympanic rim appears to be a hereditary character rather than an environmental adaptative response during life or a pathology or simply an aspect of robustness; even in juvenile Eskimos, the tympanic rim is exceptionally thick, and crania from other population groups regarded as equivalently robust (e.g.

Fuegians, New Britain) do not have a correspondingly thick tympanic rim (this study, Section 5.3.3.14; Oetteking 1930:246, Stewart 1933:495). But if the feature is primarily related to increased pneumatization of the temporal bone as suggested by Kennedy (1991:404,405) it may be merely a symplesiomorphic trait.

9.2.3.11 East Asian-European Affinity. According to temporal bone similarity, Chinese and Poundbury are very closely associated, at least as close as Bushman and Gabon or Australians, Tasmanians and New Britain. In fact, of all modern human groups, Chinese and Poundbury are least able to be distinguished from one another on the basis of temporal features. Chinese crania tend to have a thinner tympanic rim and a more vertically inclined mastoid process axis than Poundbury. The same affinity was indicated in the non-temporal discrimination analysis in this study (Sections 7.2.2 & 7.4.3), and in the studies by Luboga (1986:340) and Relethford and Harpending (1994:258-261). But Howells observed no close resemblance of European and East Asian cranial shapes, even though he found both to be most dissimilar to those of Africans and Australians (Howells 1989:16,39,46,58,63). Turner (1992b:415,425) has shown that Europeans and East Asians have distinctly different dental patterns. The 2 groups appear to differ more in non-temporal features (e.g.facial and dental) than in temporal.

9.2.4 EFFECTIVENESS OF TEMPORAL VARIATION IN DISCRIMINATING MODERN HUMANS GROUPS.

Temporal variables were found to be almost as effective as more general cranial variables in discriminating modern human groups. Meaningful comparisons cannot be made between the discrimination accuracy achieved in this study using temporal variables and the accuracy achieved in other studies in general because: (i) Most other discrimination studies use considerably more variables. The number of variables in a discriminant analysis critically affects the classification accuracy achieved; for most variables, the greater the number used the greater the degree of discrimination.

(ii) There is a tendency in discriminant studies, partly because of the use of large numbers of variables, to include many highly correlated variables (e.g. several different

measurements of overall cranial breadth). This inflates the degree of discrimination accuracy achieved since virtual duplication of measurements tailors the discrimination functions too closely to the sample used.

Therefore, comparison of effectiveness is limited to the investigation in this study in which the results of separate analyses involving the same number of temporal and non-temporal variables were compared. Nevertheless, the non-temporal variables are ones commonly used in discrimination studies and all have high between-groups variance.

Some combinations of such non-temporal variables resulted in more effective discrimination than use of temporal variables, though not greatly, suggesting there is slightly more between-groups variation in general cranial shape than in temporal features. The improvement is more noticeable if the groups are <u>not</u> regionally distinct, implying that regional distinction is more evident in temporal differences than in non-temporal differences. A wide nasal aperture and small maximum biparietal breadth are the non-temporal variables which best discriminate Australians, a result which confirms Lahr's findings (1992:271,272).

A combination of temporal and non-temporal variables was found to be more effective in discriminating modern human groups than temporal or non-temporal variables alone.

9.2.5 DISCRIMINATION OF TERMINAL PLEISTOCENE MODERN HUMANS BY TEMPORAL VARIABLES.

Discriminant analysis of a sample comprising the 6 core recent modern human groups and 3 modern human fossils, Zhoukoudian Upper Cave 101 & 102 (29-24 ka ago) and the Australian Kanalda (14 ka ago) shows that the temporal bone morphology of the 3 terminal Pleistocene fossils is well within the recent modern human range of variation. Kanalda is classified with recent Australians, -- a result consistent with distinctive Australian temporal morphology being constant for at least 14 ka. UC102 is classified with recent Chinese, but UC101 is classified with recent Australians. This may reflect a wider variation in the temporal bone morphology of Chinese modern humans 25 ka ago, including aspects characteristic of recent Australians. However, more than 3

fossils would be needed to settle the question.

The dental and general cranial morphology of the Upper Cave crania have prompted a variety of proposals as to their affinity with modern human populations. In this study, the affinities of UC101 and UC102 indicated by temporal features do not resolve the controversy but do support a number of apparently conflicting suggestions made on dental and general cranial evidence in other studies:

a) The close affinity of UC101 with recent Australians and its greater resemblance to recent Africans rather than to recent Chinese coincides exactly with the Australian/African affinity proposed by Habgood, Wright and Kamminga from studies based on general cranial features (Habgood 1985:373; Kamminga & Wright 1988:739; Kamminga 1992:384,387; Wright 1992:133).

b) The temporal morphology diversity seen in Chinese fossil crania of identical provenance (UC101, UC102) may be consistent with the diversity in general cranial appearance Weidenreich identified as "proto-Mongolian" (Weidenreich 1943:151); it may be consistent also with a possible unspecialised, early Mongolian pattern referred to by Howells which today is seen in e.g. Amerindians (Howells 1960:300,301). However, in both cases Australian/African characteristics are evident in the Upper Cave morphology.

c) The temporal evidence does not support an affinity with recent modern Chinese for both Upper Cave fossils since UC102 only was classified as Chinese. This is contrary to general cranial evidence cited by Thorne (1977:201), Wolpoff(1985:360) and Wu (1961:1004). Neither does the temporal evidence support Turner's dental evidence of a Sinodont pattern in Upper Cave crania (Turner 1992a:145, 1992:426), a claim which has been disputed (Kamminga 1992:384; Kamminga & Wright 1988:745).

These conclusions must be regarded with caution since they are drawn from the results of an analysis involving a very small fossil sample. Nevertheless, the temporal evidence confirms the difficulty of confidently associating terminal Pleistocene Chinese cranial morphology with that of any one recent modern human group.

9.3 CONTINUITY IN AUSTRALASIA:

9.3.1 COMPARISON OF TEMPORAL FEATURES IN MODERN HUMANS, AFRICAN AND ASIAN *H.ERECTUS* AND AFRICAN APES.

Variation observed in temporal bone features in modern humans, African and Asian *H.erectus* and African apes provides no support for the multiregional hypothesis of the origin of modern humans.

9.3.1.1. CONTINUITY FEATURES. Comparison of 6 descriptive and 14 quantitative temporal features in modern humans (6 regionally distinct population samples), *H.erectus* (African, Javan, Chinese representatives) and African apes (*Gorilla* and *Pan*) yielded no convincing evidence of morphological continuity in Australasia or East Asia. This is contrary to findings in studies by Frayer et al.1993:42; Habgood 1985:373,374; 1989:267,268;1992:283; Kramer 1991:455; Pope 1988:61,62,70;1991:210;1992a:3; Thorne & Wolpoff 1981:349; 1992:30,31; Turner 1992b:415; Weidenreich 1943:248-252;1949:152; Wolpoff 1985:358-360;1992a:42,54; Wolpoff & Thorne 1991:39; Wolpoff,Wu & Thorne 1984:464. No temporal feature which is likely to be derived for Asian *H.erectus* was found to be uniquely present, most frequently present or most prominent in either modern Australian or Chinese groups compared to other modern human populations. This result based on temporal variables complements the findings from other studies evaluating possible continuity traits but involving more general cranial variables (Lahr 1992:272,1994:47-49; Clark 1990:729,733; Foley & Lahr 1992:527; Groves 1989:280-283; Kamminga 1992b:379,384; Kamminga & Wright 1988:739; Lahr 1994:48-50; Lahr & Foley 1994:50; Larnach & Macintosh 1974:101,102; Lieberman 1995:176; Stringer 1990b:35,36; 1993a:179,193; Wright 1992:128,133.

9.3.1.2. AUTAPOMORPHIC FEATURES. If temporal features offer no support for regional continuity in Australasia, neither do they provide evidence to rule it out as a possibility since none of the features considered was found to be autapomorphic for Asian *H.erectus*. Consequently, Asian *H.erectus* cannot be discounted as a possible ancestor of modern humans, at least on the basis of the temporal variables

considered here.

All the descriptive temporal features observed present in Asian *H.erectus* were also observed present in modern humans, present in African *H.erectus* (with the possible exception of mastoid fissure and supratubalis), and in some cases present in apes. Whether or not mastoid fissure and supratubalis are regarded as present or absent in African *H.erectus*, they are primitive retained features in Asian *H.erectus*.

9.3.2 DESCRIPTIVE TEMPORAL FEATURES.

In recent studies by Brauer and Mapa (1992) and Kennedy (1991), mastoid fissure and medial recess were found to be symplesiomorphic traits and not Asian *H.erectus* autapomorphs. But the difficulty in assessing these features because of their continuous and complex variation was stressed (Brauer & Mapa 1992:105). In this study, an attempt was made to define the traits more precisely, take into account the continuous nature of their variation and, as with all the features investigated, extend the analysis to include their comparative occurrence in modern human populations.

None of the 6 descriptive temporal features occurred noticeably more frequently or prominently in Australians or Chinese than in all other modern human groups. Since 3 of the features (mastoid fissure, supratubalis and tympanic medial region convexity) are present in apes as well as in *H.erectus*, they must be regarded as primitive retained traits. Although not evident in apes in this study, medial recess is probably also a primitive feature since in other studies (e.g. Brauer & Mapa (1992:103); Kennedy (1991:401)) it has been observed in hominids earlier than *H.erectus*. Consequently, these features cannot be used to indicate regional continuity.

9.2.2.1. MASTOID FISSURE was proposed as a possible autapomorph of Asian *H.erectus* by Andrews (1984:174) and Stringer (1984:134). In this study the mastoid fissure was found to be common in Asian *H.erectus*, absent in the only African *H.erectus* specimen on which it could be assessed, present in *Gorilla* and present in modern humans. Kennedy (1991:401) also found the fissure absent in African *H.erectus*, though Brauer and Mapa (1992:100) judged it present in possibly 2 African *H.erectus*. However, all results indicate

that the mastoid fissure is not autapomorphic for Asian *H.erectus* and is a primitive retained feature.

The mastoid fissure is not uncommon in modern humans; 30% were found to have a fissure >1mm. (Kennedy's finding that only 10% of modern humans have a mastoid fissure, always <1 mm. wide (Kennedy 1991:401) was based on a Poundbury sample, a population which has a considerably lower incidence of the feature than other modern human groups). The frequency of occurrence of the mastoid fissure is comparatively low in Australians and no more than average in Chinese. Kennedy (1991:403) raised the possibility of a connection between this feature and cranial base flexion. Evidence was found in this study of a weak negative link between mastoid fissure incidence and cranial base flexion: the more flexed the cranial base the less likely the occurrence of a mastoid fissure.

9.3.2.2. MEDIAL RECESS. Proposed as a possible autapomorph of Asian *H.erectus* by Andrews (1984:174,175), in this study a medial recess was found present in most *H.erectus* crania, both African and Asian, absent in African apes and present in modern humans, though in only 7.7% is it wider than 1mm. Brauer and Mapa (1992:102-105) and Kennedy (1991:401-403) also discounted medial recess as an autapomorph of Asian *H.erectus* and identified it as symplesiomorphic since they found it present in both African and Asian *H.erectus*, and in earlier and later hominids. Contrary to this study, Kennedy recognised the recess as present in *Gorilla* and *Pan*, and as a usual feature in modern humans (as represented by a Poundbury sample). According to this study, the frequency in modern humans varies considerably from one group to another; it is least prominent and most often absent in Australians, and most frequently present in Chinese, Poundbury and Eskimo.

No association of the feature was detected with cranial base flexion or mastoid fissure occurrence, as suggested by Kennedy (1991:403). But a weak positive link with anterior-posterior glenoid fossa length indicates that, as suggested by Weidenreich (1943:47), the incidence of medial recess may be reduced by anterior-posterior compression of the glenoid fossa and possibly of the whole cranial base.

In modern humans the medial recess is usually associated with an entoglenoid process which is continuous with a

sphenoid spine; in 54.3% of modern humans the spine is >5mm. The spine is smallest and most frequently absent in Gabon crania; all other groups including Australians and Chinese are very similar in the expression of this feature. A sphenoid spine in conjunction with the entoglenoid process was thought to be absent in *H.erectus* but a small spine arguably may be present in Sangiran 17 and Ngandong 7 and 12.

9.3.2.3. A CONVEX TYMPANIC MEDIAL REGION was found to be the usual condition in Asian and African *H.erectus* and in apes. This contradicts the view of Larnach and Macintosh (1974:97) that a convex tympanic is a characteristic trait of Ngandong and a possible example of a continuity trait with Australians. A convex medial region occurs in modern humans, but for all groups except Andamanese a concave condition is far more frequent. The convex condition is particularly infrequent in Australians and Chinese crania.

Convexity occurrence was found to be negatively linked to tympanic height and general cranial size, implying that a convex tympanic medial region is least likely in large crania with high tympanic plates. In identifying a convex medial region of the tympanic as characteristic of Chinese *H.erectus,* Weidenreich related it to both the extreme tympanic thickness and occurrence of the medial recess (Weidenreich 1943:47,202,203); this study found no evidence of such associations.

9.3.2.4. SUPRATUBALIS. It was difficult to accurately determine the presence or absence of a supratubalis in African or Asian *H.erectus* casts, though the structure was certainly observed in at least one Ngandong specimen. However, Rightmire (1990:177,189) considered the feature characteristic of both African and Asian *H.erectus*; Weidenreich (1943:61,204) described differences in the expression of the structure in apes, Chinese *H.erectus* and modern humans. Irrespective of its presence or absence in African *H.erectus,* the supratubalis is a primitive retained feature. It was observed universally present in apes as a very prominent, robust structure and in 47.8% of modern humans in a much shorter, finer and more variable form. A supratubalis is noticeably most frequently absent in Chinese crania, and most frequently present in Australians and Eskimos, suggesting a possible link between supratubalis occurrence and general tympanic robusticity.

However, no association with tympanic rim thickness was detected.

9.3.2.5. TEGMEN TYMPANI is absent in apes and apparently absent in African and Asian *H.erectus* but difficult to assess on casts. Tegmen tympani is rarely absent in modern humans with the notable exception of the comparatively flat-based Gabon crania. This feature may be autapomorphic for modern humans, but further data from other hominids is needed to decide if that is the case.

9.3.2.6. FORAMEN OF HUSCHKE is absent in apes and present in about a fifth of modern human adults. The incidence is most frequent in Andamanese and Eskimos, intermediate in Chinese and particularly low (7%) in Australians. (For Australians, Krogman reported 6-7% (1932:410) and Kellock & Parsons 7.5% (1971:237)). Foramen of Huschke occurrence is negatively linked to tympanic rim thickness, but Eskimos are a remarkable exception to this trend. The condition is evident in only one *H.erectus*, the Asian juvenile *Sinanthropus* IIIE. More data is needed from other hominids to evaluate the feature's possible evolutionary significance.

9.3.3 QUANTITATIVE TEMPORAL FEATURES. Neither Australians nor Chinese are more similar than all other modern human groups to Asian *H.erectus* in any quantitative temporal feature which is likely to be derived for Asian *H.erectus*.

9.3.3.1. FEATURES IN WHICH AFRICAN AND ASIAN *H.ERECTUS* DIFFER. Of the 14 quantitative temporal features considered there are only 3 in which Asian and African *H.erectus* notably differ and in which the derived condition may be that expressed in Asian *H.erectus* and therefore potential Australasian or East Asian continuity traits. The TYMPANIC PLATE LATERAL RIM is THICKER and more INDENTED, and the GLENOID FOSSA LENGTH/WIDTH RATIO greater in Asian than in African *H.erectus*.

In none of the 3 features are the Australians more similar than all other modern human groups to the Asian *H.erectus* condition, though with Eskimos, they are the most similar of the modern humans in tympanic rim thickness and glenoid fossa length/width ratio. However, unlike Eskimos,

Australians bear greater resemblance in those features to other modern humans than to Asian *H.erectus*. Thickness in the tympanic rim corresponds to a low maximum cranial breadth and possibly to increased pneumatization of the temporal bone, a connection proposed by Kennedy who regarded temporal pneumatization as a symplesiomorphic process (Kennedy 1991:404,405). The tympanic rim of African *H.erectus* and even more so of apes, is thin in relation to their cranial breadth proportions.

Chinese, with Poundbury, are the most similar of the modern human groups to Asian *H.erectus* in having the most deeply indented tympanic rim, but in the Chinese this is more likely to be related to a thinner tympanic rim in a very wide cranium and not to a very prominent supramastoid crest as in Asian *H.erectus*.

9.3.3.2. FEATURES IN WHICH NGANDONG DIFFER FROM OTHER *H.ERECTUS*. Ngandong differ noticeably from the other *H.erectus* groups in 3 temporal features: a larger PETROUS-TYMPANIC ANGLE, a more acute SUPRAMEATAL CREST ANGLE and a more sagitally inclined TYMPANIC AXIS. All 3 trends which place Ngandong values between those of other *H.erectus* and modern humans are consistent with Ngandong showing greater evolutionary advancement (in the sense of being morphologically more similar to modern humans) than do African and other Asian *H.erectus*. However, evidence of continuity in these traits from Ngandong to modern Australians is not convincing.

Australians with Bushman are the modern humans most similar to Ngandong in having the smallest petrous-tympanic angle; but this indicates no more than the primitive polarity of the feature as expressed in modern humans, since <u>all</u> modern groups are more similar to Ngandong in this features than they are to other *H.erectus* representatives. Also, in all 3 features, Australians resemble other modern humans more closely than they resemble Ngandong. Mastoid transverse thickness is one of the features which affects tympanic orientation and consequently, the petrous-tympanic angle, such that the thicker the mastoid, the more coronally oriented the tympanic and the smaller the petrous-tympanic angle. Of the 6 core groups, Australians have the greatest mastoid transverse depth and with Eskimos, the most coronally oriented tympanic.

Australians and Africans are linked by a more acute petrous-tympanic angle and a more sagitally oriented petrous than other modern human groups, but as Lahr (1992:91, 1994:35,41) also noted, although the petrous orientation difference is significant, the feature is symplesiomorphic so cannot be regarded as a continuity trait.

Across the species, apes to *H.erectus* to modern humans: (i) petrous-tympanic angle and petrous angle increase as the petrous and tympanic shorten, as the cranial base becomes more flexed and as cranial breadth/length ratio decreases. Asymmetry considerations in modern humans suggest the further possibility of a link between orientation of the petrous and tympanic axes with jugular fossa size and associated intracranial blood supply. (ii) suprameatal crest angle decreases as the cranial base flexion increases and cranial breadth/length ratio decreases. A connection between a more horizontally inclined suprameatal crest and lower facial prognathism is possible but was not quantified in this study.

Within modern humans, a negative association was observed between nasal aperture width and petrous sagittal angle (and hence petrous-tympanic angle). Nasal aperture width is an important predictor in discriminating modern human groups, particularly Australians and Eskimos. Unlike nasal aperture height, the width shows independence of cranial size, and is most likely an hereditary characteristic and a morphological adaptive response to the degree of humidity and temperature of inhaled air (Franciscus & Trinkhaus 1988:517; Carey & Steegmann 1981:313; Wolpoff 1968:421). The relationship between petrous orientation and nasal aperture width was not pursued further in this study.

9.3.3.3. POSSIBLE SHARED DERIVED FEATURES FOR AFRICAN AND ASIAN *H.ERECTUS*. Australians are marginally the most similar of modern humans to all *H.erectus* in having a transversely DEEP MASTOID PROCESS. Since there is no notable difference in the feature between African and Asian *H.erectus*, no inference can be made about regional continuity. The resemblance represents no more than the primitive polarity in modern humans of what may be a shared derived trait for African and Asian *H.erectus*. This is also true of the non-temporal ratio representing the curvature of the occipital bone (chord to arc ratio). All *H.erectus* groups with their high incidence of

prominent occipital tori have a significantly more sharply angled occipital than *Pan* or modern humans. Poundbury is the modern human group closest to them, but because of a tendency to have occipital buns, not tori (not quantified in this study). Also, the resemblance of the Poundbury occipital to that of other modern humans is greater than its resemblance to the *H.erectus* occipital.

9.3.3.4. FEATURES IN WHICH *H.ERECTUS* IS INTERMEDIATE BETWEEN MODERN HUMANS AND APES. Such features are likely to be symplesiomorphs and therefore ineligible as continuity traits.

INTERNAL PETROUS TRANSVERSE ANGLE. Weidenreich (1943:67,206) noted the internal petrous transverse angle decreases, i.e. the posterior endocranial petrous wall becomes more vertically inclined from apes to Asian *H.erectus* to modern humans. This is verified by results of an analysis involving African *H.erectus* also. There is some support for his proposal that the change corresponds to increasing cranial base flexion and anterior migration of the foramen magnum. The angle magnitude was similar for African and Asian *H.erectus,* though there was only one representative of each. The number of crania in which this feature could be observed was far too small to consider the comparative similarity of modern human groups to Asian *H.erectus,* but on the evidence available internal petrous transverse angle can be neither an Asian *H.erectus* autapomorphy nor a continuity trait.

ENDINION-INION SEPARATION, although not a temporal feature, was tested as a possible autapomorphic trait or continuity trait. Andrews (1984:174), Stringer (1984:134) and Wood (1984:105-7) proposed it as a possible unique derived trait of Asian *H.erectus.* This analysis found that all *H.erectus* are intermediate between *Gorilla* and modern humans in the position of endinion relative to inion. On all ape and *H.erectus* crania, inion is placed higher than endinion. In modern humans it is more usual for endinion to be a little higher than inion, but 2 groups, Chinese and Poundbury, have mean values indicating inion slightly above endinion, the primitive polarity of the feature for humans. (This was true also of the Amerindian sample representing modern humans in Kennedy's analysis of this feature (Kennedy 1991:400)). It has

been said of Australians that endinion is low relative to inion (e.g.Burkitt & Hunter 1922:51) but results of this study show that the Australian endinion-inion separation mean is intermediate compared to other modern human means, and all modern human groups are more similar to each other in this feature than any is to *H.erectus*. As Brauer and Mapa (1992:98,99) and Kennedy (1991:399-401) concluded, endinion-inion separation cannot be an autapomorphic Asian *H.erectus* trait. Nor can it be claimed as an Australasian or East Asian continuity trait.

As Stringer (1984:135) and Brauer and Mapa (1992:98) have pointed out, endinion-inion separation is the result of a complex interaction of at least 2 important and separate factors: internally, the endocranial proportions and externally the degree of development of the nuchal muscles. This study found no aspect of the temporal bone directly associated with endinion-inion separation.

9.4 SUMMARY CONCLUSIONS

The results of this study do not support the Multiregional model of modern human origins either on the existence of temporal continuity traits or on the pattern of clustering of modern groups based on temporal similarities.

No temporal feature was found which can be regarded as a continuity trait from Australians (or Australo-melanesians) to S.E. Asian H.erectus or to Asian *H.erectus* in general. Neither was a temporal continuity trait found from modern Chinese to *Sinanthropus* or to Asian *H.erectus* in general.

Modern human populations can be discriminated from one another by temporal bone features almost as effectively as by more general cranial features.

Nevertheless, as has been found in other studies using general cranial variables, the between-groups variation of temporal characters is small relative to within-groups variation, a pattern most readily reconciled with a recent divergence of modern humans.

The pattern of clustering of modern human groups revealed by temporal features is similar to that determined by more general cranial features in many other craniometric variation studies: Australo-melanesians are more similar to African groups than either is to East Asians; in fact, Chinese is the group least like Australians in almost every aspect of the temporal bone. Australians show closest affinity with New Britain and to less extent, Tasmanians. Bushman show close affinity with Africans;

However, two less usual results are noteworthy: On the basis of temporal similarity, (i) no two groups show a closer affinity than East Asians (Chinese) and Europeans (Poundbury), and (ii) all groups are closer to each other than any is to Eskimos, although Chinese are linked to Eskimos through the South American Fuegians. The Eskimo isolation reflects the extreme dimensions of their temporal bone.

The Australian Aborigine temporal bone is not remarkably

different to that of all other modern human groups and is not more similar to the temporal bone of *H.erectus* (Ngandong, Javan or East Asian). Only the Eskimo temporal bone is remarkable, and that mainly because of an exceptionally thick tympanic lateral rim.

The temporal bone feature in which Australians differ most from other groups is an acutely angled, long and narrow mastoid process, a feature related to muscles controlling aspects of the orientation of the head. Australians with Africans, have a distinctively small petrous-tympanic angle and sagitally inclined petrous pyramid, but these features are symplesiomorphic.

Several features, one occipital and the rest temporal, proposed as possible autapomorphs for East Asian *H.erectus* were tested and found not to be so since they are also present in African *H.erectus* and modern humans, and are symplesiomorphic; most are also present in African apes.

Some interesting associations of temporal features with other cranial features were detected in modern humans:

Much of the asymmetry involving petrous and tympanic axes orientation and mastoid process size appears to be directly associated with jugular fossa and sigmoid sulcus asymmetry and consequently, indirectly with an intracranial blood supply asymmetry. This may further imply a relationship between one aspect of intracranial blood supply and changes in petrous and tympanic axes orientation from apes to *H.erectus* to modern humans.

In modern humans, the tympanic axis becomes more sagitally inclined the more anteriorly positioned the foramen magnum, a trend consistent with the increase in petrous-tympanic angle as the foramen magnum migrates anteriorly from apes to modern humans. (From data available in this study, *H.erectus* could not be included in the trend). The expansion of the cerebellum in hominid evolution is likely to be one important factor in the anterior advancement of the foramen magnum and endocranial aspects of the petrous orientation such as an increasingly vertical petrous posterior wall.

Mastoid fissure occurrence shows a weak negative association with cranial base flexion, and this relationship may apply also across species from apes to *H.erectus* to modern humans. All other qualitative temporal variables examined are independent of cranial base flexion.

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APPENDIX

TABLE A.4.1. SOURCES OF POPULATION SAMPLES

POPULATION SAMPLE	NO.	-- C O L L E C T I O N -- NHM	CAM	EDU	OXI	OXM
ANDAMANESE	50	44	6			
AUSTRALIAN	76	69	7			
BUSHMAN	21	7	7	7		
CHINESE	50	44	6			
ESKIMO	52	46	6			
FUEGIAN	16	15	1			
GABON	50	50				
NEW BRITAIN	50		50			
POUNDBURY	50	50				
TASMANIAN	14	7	3		3	1
VEDDAH	18	14	4			
TOTAL	447	346	90	7	3	1

NHM = Palaeontology Department, The Natural History Museum, London
CAM = Duckworth Collections, Department of Biological Anthropology, Cambridge.
EDU = Department of Anatomy, University of Edinburgh.
OXI = Institute of Biological Anthropology, Oxford.
OXM = University Museum Oxford.

TABLE A.4.2 CRANIAL SAMPLE FOR ENDOCRANIAL MEASUREMENT OF PETROUS TRANSVERSE ANGLE

14 of the 15 crania are from the Natural History Museum, London collection. The Tasmanian is from Cambridge. Only one side could be measured on 2 specimens, as indicated by "L" or "R".

ANDAMANESE		AUSTRALIAN		CHINESE	
8.0322	L&R	30/990	L&R	60/751	L&R
8.0326	L&R	50/998	L&R		
8.0327	L&R	ij7	L&R	ESKIMO	
8.0405	L&R	1883.9.29.1	R	FC836	L&R
GABON		1897.10.10.2	L&R		
6.7.40	L&R	BUSH		TASMANIAN	
6.7.86	L&R	xxviE.21	L&R	2099	L

TABLE A.4.3 JUVENILE CRANIAL SAMPLE

CRANIUM	AGE yrs.	SOURCE	CRANIUM	AGE yrs.	SOURCE	CRANIUM	AGE yrs.	SOURCE
ANDAMANESE			BUSHMAN			GABON		
8.0234	14	NHM	63/422	9	NHM	1864:6.7.2	6	NHM
8.051	12	NHM	63/424	8.5	NHM	1864:6.7.20	15	NHM
8.0551	7	NHM	1959:22/4/1	8	NHM	1864:6.7.72	10	NHM
AUSTRALIAN			Exxvi.12	13	EDU	1880:7.2.8	8	NHM
30/444	5	NHM	Exxvi.19	2	EDU	1880:7.2.9	7	NHM
30/980	9.5	NHM	ESKIMO			NEW BRITAIN		
50/996	13.5	NHM	BD1184	10	NHM	3355	6.5	CAM
1971,1/8/7	9.5	NHM	86:4/27/5	7	NHM	3822	12	CAM
CHINESE			86:4/27/6	4.5	NHM	POUNDBURY		
7.6561	3.5	NHM	91:12/18/2	10	NHM	PC.158	9	NHM
7.6863	4	NHM	TASMANIAN			PC.1255	6	NHM
			80/446	15	NHM	PC.1404	8	NHM

TABLE A.4.4 IDENTITY OF CRANIA IN POPULATION SAMPLES

The catalogue code of each cranium in the study is given, together with the collection to which it belongs.

COLL.	CRANIUM
	ANDAMANESE
NHM	1861.8.22.1
NHM	1864.8.22.1
NHM	1865.5.26.1
NHM	1884.9.5.1
NHM	1890.5.14.1
NHM	1905.11.25.1
NHM	1905.11.25.2
NHM	1905.11.25.3
NHM	1911.11.14.4
NHM	1931.6.7.1
NHM	1931.6.7.2
NHM	1931.6.7.3
NHM	1956.17.10.1
NHM	1956.17.10.2
NHM	1968.8.8.49
NHM	IM20.4
NHM	IM20.17
NHM	IM20.531
NHM	IM20.1038
NHM	8.00.1
NHM	8.0205
NHM	8.0206
NHM	8.0207
NHM	8.0209
NHM	8.0233
NHM	8.0235
NHM	8.0301
NHM	8.0302
NHM	8.0306
NHM	8.0307
NHM	8.0308
NHM	8.0310
NHM	8.0311
NHM	8.0321
NHM	8.0322
NHM	8.0326
NHM	8.0327
NHM	8.0328
NHM	8.0329
NHM	8.0330
NHM	8.0331
NHM	8.035
NHM	8.0401
NHM	8.0402
CAM	1B
CAM	4B
CAM	9B
CAM	11B
CAM	14B
CAM	5W

COLL.	CRANIUM
	AUSTRALIAN
NHM	AUS20/1
NHM	AUS20/971
NHM	AUS20/972
NHM	AUS20/973
NHM	AUS20/974
NHM	AUS20/975
NHM	AUS20/976
NHM	AUS30/55
NHM	AUS30/56
NHM	AUS30/435
NHM	AUS30/436
NHM	AUS30/438
NHM	AUS30/439
NHM	AUS30/440
NHM	AUS30/441
NHM	AUS30/442
NHM	AUS30/443
NHM	AUS30/978
NHM	AUS30/979
NHM	AUS30/981
NHM	AUS30/982
NHM	AUS30/983
NHM	AUS30/984
NHM	AUS30/986
NHM	AUS30/987
NHM	AUS30/988
NHM	AUS30/989
NHM	AUS30/990
NHM	AUS40/1
NHM	AUS40/993
NHM	AUS50/532
NHM	AUS50/533
NHM	AUS50/994
NHM	AUS50/998
NHM	AUS50/1002
NHM	AUS60/3
NHM	AUS60/4
NHM	AUS60/57
NHM	AUS60/1004
NHM	AUS60/1006
NHM	AUS60/1008
NHM	AUS635
NHM	AUS1009
NHM	AUS1010
NHM	AUS1011
NHM	AUS1013
NHM	AUS1014
NHM	AUS1015
NHM	AUS1016
NHM	AUS1016c

COLL.	CRANIUM
	AUSTRALIAN
NHM	1j7
NHM	1862.2.8.1
NHM	1862.2.8.2
NHM	1883.9.29.1
NHM	1884.9.5.5
NHM	1888.12.10.1
NHM	1897.10.10.1
NHM	1897.10.10.2
NHM	1897.10.10.3
NHM	1897.10.10.4
NHM	1900.6.1.25
NHM	1923.12.15.1
NHM	1937.2.5.1
NHM	1944.10.18.1
NHM	1944.10.18.3
NHM	1968.8.8.69
NHM	1968.8.8.70
NHM	1968.8.8.71
NHM	1971.1.8.6
CAM	OC.0.0.1
CAM	#5
CAM	#4
CAM	2164
CAM	2102
CAM	2105
CAM	2115
	BUSHMAN
NHM	AF63.419
NHM	AF63.420
NHM	AF63.421
NHM	AF63.426
NHM	AF63.1068
NHM	AF63.1072
NHM	94.4.25.2
EDU	EDxxvi.E11
EDU	EDxxvi.E14
EDU	EDxxvi.E16
EDU	EDxxvi.E17
EDU	EDxxvi.E21
EDU	EDxxvi.E42
EDU	EDxxvi.E12
CAM	1738
CAM	1758 **
CAM	3732
CAM	6109
CAM	2xii1914
CAM	5102
CAM	5585

** cranium deleted from multivariate analyses.

TABLE A.4.4 IDENTITY OF CRANIA IN POPULATION SAMPLES (Contd.)

COLL.	CRANIUM
	CHINESE
NHM	7.6101
NHM	7.6102
NHM	7.6121
NHM	7.6122
NHM	7.6302
NHM	7.6304
NHM	7.6305
NHM	7.6306
NHM	7.6308
NHM	7.631
NHM	7.6331
NHM	7.6332
NHM	7.6333
NHM	7.6335
NHM	7.635
NHM	7.6381
NHM	7.6383
NHM	7.6385
NHM	7.6386
NHM	7.6421
NHM	7.6502
NHM	7.6503
NHM	7.651
NHM	7.6532
NHM	7.6565
NHM	7.6566
NHM	7.6567
NHM	7.6568
NHM	7.6569
NHM	7.6570
NHM	7.6571
NHM	7.685
NHM	7.6981
NHM	7.6989
NHM	7.699
NHM	AS.60/468
NHM	AS.60/469
NHM	AS.60/470
NHM	AS.60/749
NHM	AS.60/750
NHM	AS.60/751
NHM	AS.60/753
NHM	1862:7/5/1
NHM	1879:11/21/118
CAM	1760
CAM	1761
CAM	1762
CAM	21.0.3
CAM	21.0.5
CAM	21.0.7

COLL.	CRANIUM	
	ESKIMO	
NHM	FC807	
NHM	FC810	
NHM	FC811	
NHM	FC812	
NHM	FC813	
NHM	FC814	
NHM	FC815	
NHM	FC816	
NHM	FC817	
NHM	FC818	
NHM	FC819	
NHM	FC824	
NHM	FC825	
NHM	FC831	*
NHM	FC832	*
NHM	FC833.2	
NHM	FC833.3	
NHM	FC836	
NHM	AM10.836	
NHM	AM10.837	
NHM	AM10.838	
NHM	AM10.839	
NHM	AM10.840	
NHM	AM10.842	
NHM	AM10.843	
NHM	AM10.844	
NHM	AM10.845	
NHM	AM10.846	
NHM	AM10.847	
NHM	AM10.848	
NHM	AM10.852	*
NHM	BD1172	
NHM	BD1174	
NHM	BD1175	
NHM	BD1176	
NHM	BD1177	
NHM	BD1178	
NHM	BD1179	
NHM	BD1180	
NHM	BD1183	
NHM	BD1185	*
NHM	BD1186	*
NHM	86.4.27.1	
NHM	86.4.27.2	
NHM	86.4.27.3	
NHM	86.4.27.4	
CAM	1833	
CAM	1934.C	
CAM	AM1.0.2	
CAM	AM1.0.3	
CAM	AM1.0.7	
CAM	AM1.0.8	

COLL.	CRANIUM
	FUEGIAN
CAM	4498
NHM	FC.1025
NHM	FC.1025.1
NHM	FC.1025.2
NHM	FC.1025.3
NHM	FC.1025.4
NHM	FC.1025.5
NHM	FC.1025.6
NHM	FC.1025.7
NHM	FC.1025.8
NHM	FC.1026
NHM	FC.1027
NHM	1899:4/27/1
NHM	1902:9/18/1
NHM	1938:8/10/1
NHM	AM:80/4
	GABON, AFRICA
NHM	6.7.1
NHM	6.7.8
NHM	6.7.11
NHM	6.7.14
NHM	6.7.18
NHM	6.7.28
NHM	6.7.31
NHM	6.7.32
NHM	6.7.34
NHM	6.7.37
NHM	6.7.40
NHM	6.7.47
NHM	6.7.49
NHM	6.7.50
NHM	6.7.53
NHM	6.7.55
NHM	6.7.57
NHM	6.7.59
NHM	6.7.63
NHM	6.7.69a
NHM	6.7.71
NHM	6.7.73
NHM	6.7.76
NHM	6.7.77
NHM	6.7.78
NHM	6.7.83
NHM	6.7.87
NHM	6.7.89
NHM	6.7.12
NHM	6.7.17
NHM	6.7.22
NHM	6.7.23
NHM	6.7.38
NHM	6.7.41

* crania from northeast Canada.

TABLE A.4.4 IDENTITY OF CRANIA IN POPULATION SAMPLES (Contd.)

COLL.	CRANIUM
	GABON, AFRICA
NHM	6.7.42
NHM	6.7.48
NHM	6.7.54
NHM	6.7.66
NHM	6.7.68
NHM	6.7.70
NHM	6.7.75
NHM	6.7.84
NHM	6.7.86
NHM	6.7.90
NHM	6.7.91
NHM	7.2.10
NHM	7.2.12
NHM	7.2.17
NHM	7.2.19
NHM	7.2.39
	NEW BRITAIN
CAM	1827
CAM	3321
CAM	3323
CAM	3324
CAM	3325
CAM	3327
CAM	3328
CAM	3329
CAM	3330
CAM	3331
CAM	3332
CAM	3333
CAM	3334
CAM	3335
CAM	3336
CAM	3337
CAM	3339
CAM	3341
CAM	3342
CAM	3343
CAM	3345
CAM	3347
CAM	3348
CAM	3349
CAM	3350
CAM	3353
CAM	3354
CAM	3356
CAM	3357
CAM	3358
CAM	3359
CAM	3360
CAM	3361
CAM	3362

COLL.	CRANIUM
	NEW BRITAIN
CAM	3363
CAM	3364
CAM	3365
CAM	3366
CAM	3368
CAM	3369
CAM	3370
CAM	3371
CAM	3375
CAM	3376
CAM	3380
CAM	3381
CAM	3383
CAM	3384
CAM	3385
CAM	3386
	POUNDBURY
NHM	PC94
NHM	PC110
NHM	PC114
NHM	PC144
NHM	PC165
NHM	PC185
NHM	PC207
NHM	PC284
NHM	PC289
NHM	PC309
NHM	PC310
NHM	PC314
NHM	PC322
NHM	PC323
NHM	PC343
NHM	PC349
NHM	PC499
NHM	PC500
NHM	PC543
NHM	PC581
NHM	PC625
NHM	PC640
NHM	PC677
NHM	PC702
NHM	PC705
NHM	PC734
NHM	PC736
NHM	PC749
NHM	PC750
NHM	PC753
NHM	PC776
NHM	PC785
NHM	PC793
NHM	PC794a

COLL.	CRANIUM
	POUNDBURY
NHM	PC796
NHM	PC804
NHM	PC821
NHM	PC871
NHM	PC889
NHM	PC904
NHM	PC913
NHM	PC923
NHM	PC924
NHM	PC937
NHM	PC1021
NHM	PC1032
NHM	PC1045
NHM	PC1050
NHM	PC1217
NHM	PC1384
	TASMANIAN
NHM	TAS80/445
NHM	TAS80/446
NHM	TAS80/1020
NHM	TAS80/1022
NHM	1894,1/20/1
NHM	1917,10/29/1
NHM	1109:1 **
CAM	CAM.2096
CAM	CAM.2099 **
CAM	CAM.2100 **
OX1	OA.80/1017
OX1	OX.80/1019
OX1	80/1023
OXM	OUM17113
	VEDDAH
NHM	56.2:736
NHM	56.2:737
NHM	56.2:738
NHM	56.2:739
NHM	56.2:740
NHM	56.2:742
NHM	1949:12.7.2
NHM	1949:12.7.3
NHM	1949:12.7.4
NHM	1949:12.7.8
NHM	1968:8.8.35
NHM	1968:8.8.37
NHM	1968:8.8.38
NHM	1968:8.8.39
CAM	AS54.0.1
CAM	6100
CAM	6101
CAM	6102

** crania deleted from multivariate analyses.

SEX DISCRIMINANT FUNCTION TEST

Utterschaut (1986:243) proposed a "race-independent" sex discriminant function: 0.35 GOL + 0.54 ZYB + 0.58 NLH + 0.49 NLB
Its effectiveness as a means of sexing crania in this study was assessed by applying the function to data from a known-sex cranial sample (27 female, 27 male) from the Spitalfield collection at the Natural History Museum, London. The results are recorded in Table A.4.5 (Cranial code, actual sex and sex discriminant score) and depicted in Fig.A.4.1.

The resulting misclassification rate of 22.2% for males, 3.7% for females and 12.3% overall, is too high for use of the discriminant function to sex crania in this study.

TABLE A.4.5 SPITALFIELD CRANIAL SAMPLE

CRANIUM	SEX	DIS.SCORE	CRANIUM	SEX	DIS.SCORE	CRANIUM	SEX	DIS.SCORE
2667	F	157.1	2465	F	168.8	2207	M	174.9
2142	F	159.4	2099	F	169.0	2661	M	174.9
2750	F	161.4	2500	F	169.1	2173	M	176.0
2399	F	161.5	2098	F	169.4	2187	M	176.1
2296	F	162.7	2439	M	169.4	2167	M	176.6
2327	F	164.1	2872	F	169.5	2063	M	177.0
2152	F	164.2	2474	M	169.7	2255	M	178.2
2178	M	164.9	2809	F	169.9	2712	M	178.4
2498	F	164.9	2259	F	170.1	2162	M	179.1
2171	M	165.0	2728	M	170.1	2186	M	179.4
2860	F	165.3	2843	F	170.3	2419	M	179.8
2368	F	165.7	2518	F	170.5	2812	M	179.8
2300	F	165.8	2070	F	170.7	2622	M	180.1
2708	F	166.5	2913	M	171.0	2406	M	180.4
2189	F	167.2	2910	M	172.8	2182	M	180.6
2134	F	167.6	2418	M	173.0	2254	M	182.7
2817	F	168.1	2298	F	173.3	2811	M	183.8
2301	F	168.5	2363	M	173.3	2671	M	185.2

Fig.A.4.1 DISTRIBUTION OF SEX DISCRIMINANT SCORES FOR 54 SPITALFIELD CRANIA

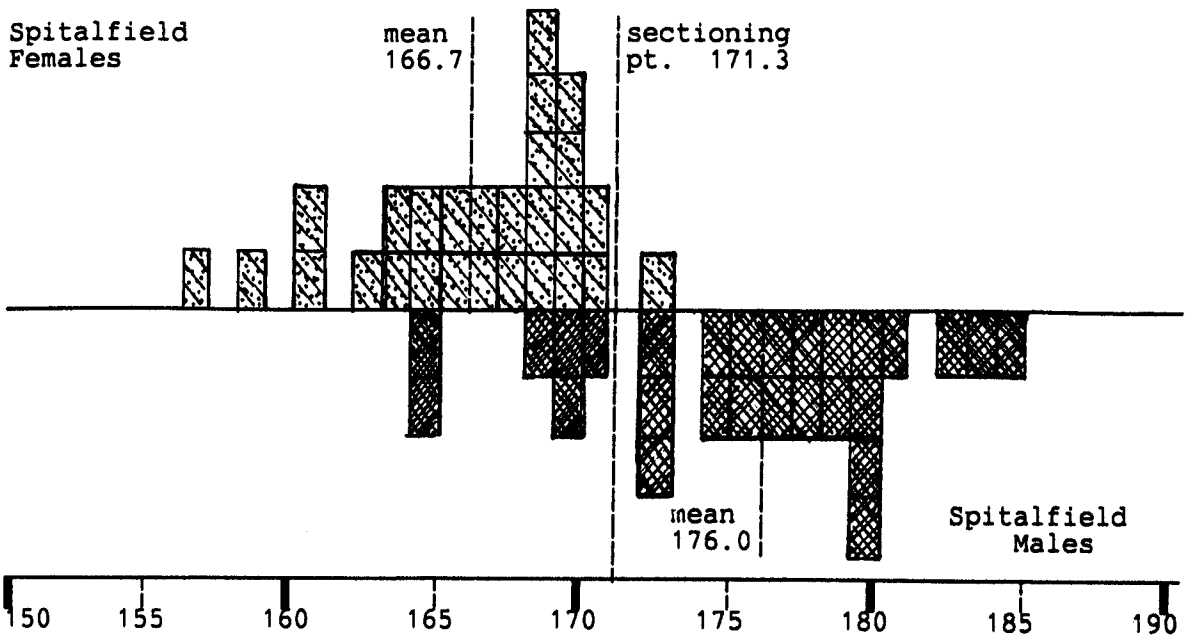

TABLE A.4.6 INSTRUMENTS & AIDS TO MEASURING:

CODE	INSTRUMENT/ AID	INST.SOURCE	RANGE	DIVISION
CC	Coordinate Caliper	GPM	220 mm.	1 mm.
DC	Sliding Caliper --dial	Mitutoyo	150 mm.	0.02 mm.
DC2	Sliding Caliper --dial	Helios	270 mm.	0.05 mm.
SC	Spreading Caliper	GPM	250 mm.	1 mm.
T	Measuring Tape	Hoechstmass	150 cm.	1 mm.
R	Ruler	Helix J01	150 mm.	1 mm.
P	Protractor	Linex 903	180 °	1 degree
D	Dividers	Rotring		
ED	Viewing Box	-		
	Sighting Tube-from Dioptrograph	GPM	---	---
DM	Dental Mirror	Ullman A-2	---	---
I	Optosil P Plus Impression Material & Xantopren Activator	Bayer Dental	---	---
K	Cuttingg Knife	Olfa	---	---
GB	Feeler Gauge	Draper	0.05-1.00mm.blades	

TABLE A.4.7 SOURCES OF LANDMARK & MEASUREMENT DEFINITIONS

AD Aiello & Dean, 1990:51-53.	ML Lahr, 1993:63,342,343.
PB Brown, 1989:10-13.	RM Martin, 1928:627-630.(The numbers in brackets are the Martin definition nos.)
G Gray's Anatomy,1989:364,365.	WWH Howells, 1973:165-182.
HC Hinton & Carlson, 1979:327.	TW White et al.,1991:65-68.
JJH Hublin, 1978:79,80.	

TABLE A.4.8 ANTHROPOMETRIC LANDMARKS

CODE	LANDMARK	SOURCE	CODE	LANDMARK	SOURCE	CODE	LANDMARK	SOURCE
as	asterion	WWH	ho	hormion	AD	g	glabella	PB
ba	basion	"	FH	Frankfurt Horizontal	"	op	opisthocranion	"
br	bregma	"	iam	int.auditory meatus	G	st	staphylion	"
la	lambda	"	iop	int.occipital protruberance	"	eg	entoglenoid process	TW
na	nasion	"				sc	suprameatal crest	"
o	opisthion	"						
i	inion	JJH						

TABLE A.4.9. MEASUREMENTS

For each measurement, the variable code, the source of measurement definition and the instrument(s) used to take the measurement are recorded in this table.
* derived variables, (L) left, (R) right, (Av) average of L & R.

No.	CODE	TEMPORAL VARIABLE	INST.	SOURCE
2	ATANGS	Angle of the tympanic plate anterior side (L)	ED,P,R	
3	ATANGSR	Angle of the tympanic plate anterior side (R)	ED,P,R	
7	BANT	Distance of basion perpendicular and anterior to bitympanic line	ED,DC	
12	EANG	External Auditory Meatus angle, long axis	ED,P,R	
13	EDIAM	External Auditory Meatus long axis diameter	DC	
14	ELANG	External Auditory Meatus angle, lower side	ED,P,R	
17	EUANG	External Auditory Meatus angle, upper side	ED,P,R	
21	FPOS	Distance of foramen magnum centre perpendicular and posterior to bitympanic line	*	
24	GAP	Glenoid fossa anterior/posterior length (L)	DC	
25	GFA	Glenoid fossa area (L)	*	HC
26	GFD	Glenoid fossa depth (L)	I,DC,K	
27	GFIDX	Glenoid fossa ant.-post./med.-lat.ratio (L)	*	
28	GL1	Glenoid fossa length 1 (L)	DC	HC
29	GL2	Glenoid fossa length 2 (L)	DC	HC
30	GL3	Glenoid fossa length 3 (L)	DC	HC
31	GFV	Glenoid fossa volume (L)	*	
32	GML	Glenoid fossa medial-lateral width (L)	DC	
37	MANG	Mastoid process axis angle (L)	ED,P,R	
38	MPD	Mastoid process depth, transverse axis (Av)	*	WWH
39	MPDL	Mastoid process depth, transverse axis (L)	DC	(WWH)
40	MPDR	Mastoid process depth, transverse axis (R)	DC	(WWH)
41	MPL	Mastoid process length, long axis (L)	ED,DC	
42	MPV	Mastoid process volume (Av)	*	
43	MPVL	Mastoid process volume (L)	*	
44	MPWAV	Mastoid process width (Av)	*	
45	MPW	Mastoid process width (L)	DC	
46	MPWR	Mastoid process width (R)	DC	
47	MSCANG	Mastoid-suprameatal crest angle (L)	*	
63	PANGS	Petrous pyramid axis sagittal angle (L)	ED,P,R	
64	PANGSR	Petrous pyramid axis sagittal angle (R)	ED,P,R	
65	PIANGT	Petrous internal transverse angle (L)	I,K,P	
66	PIANGTR	Petrous internal transverse angle (R)	I,K,P	
67	PPLAV	Petrous pyramid length (Av)	*	
68	PPL	Petrous pyramid length (L)	DC	
69	PPLR	Petrous pyramid length (R)	DC	
70	PTANG	Petrous-tympanic axes angle (L)	*	(ML)
71	PTANGR	Petrous-tympanic axes angle (R)	*	(ML)
72	SCANG	Suprameatal crest angle (L)	ED,P,R	
79	TANGS	Tympanic plate axes angle (L)	ED,P,R	
80	TANGSR	Tympanic plate axes angle (R)	ED,P,R	
81	TIND	Tympanic plate lateral rim indent (Av)	*	
82	TPH	Tympanic plate height (L)	DC,D	
83	TPL	Tympanic plate length (L)	DC	
84	TSQH	Temporal squamous height (L)	ED,DC	
85	TTHK	Tympanic plate lateral rim thickness (Av)	*	
86	TTHKL	Tympanic plate lateral rim thickness (L)	DC	
87	TTHKR	Tympanic plate lateral rim thickness (R)	DC	

TABLE A.4.9 MEASUREMENTS (Contd.)

NO.	CODE	NON-TEMPORAL VARIABLE	INST.	SOURCE
1	ASB	Biasterionic breadth	DC2	WWH
4	AUB	Biauricular breadth	SC	WWH
5	AUBEAM	Breadth between suprameatal crests directly above most lateral point on tympanic rims	DC2	
6	BANG	Base angle (staphylion-hormion-basion)	*	
8	BBH	Basion-bregma height	SC	WWH
9	BHO	Basion-hormion length	DC	RM(6a)
10	BIEAM	Breadth between L & R tympanic lateral rims	DC2	
11	BV	Perpendicular distance from staphylion-opisthion line to basion	CC	
15	ENIN	Endinion-inion separation	*	
16	ENOP	Endinion-opisthion chord	DC,DM	
18	FANG	Foramen magnum angle (staphylion-basion-opisthion)	*	
19	FMB	Foramen magnum width	DC	RM(16)
20	FML	Foramen magnum length	DC	WWH("FOL")
22	FRA	Frontal (nasion-bregma) arc	T	
23	FRC	Frontal (nasion-bregma) chord	DC	WWH
33	GOL	Glabella-opisthocranion length	SC	WWH
34	HOV	Perpendicular distance from staphylion-basion line to hormion	CC	
35	INOPC	Inion-opisthion chord	DC	
36	LINC	Lambda-inion chord	DC	
48	NLA	Nasal aperture area	*	
49	NBHX	Nasal aperture breadth/height ratio	*	
50	NLB	Nasal aperture breadth	DC	WWH
51	NLH	Nasal aperture height (Av)	*	WWH
52	NLHL	Nasal aperture height (L)	DC	(WWH)
53	NLHR	Nasal aperture height (R)	DC	(WWH)
54	NOL	Nasion-opisthocranion length	SC	WWH
55	OCA	Occipital (lambda-opisthion) arc	T	
56	OCC	Occipital (lambda-opisthion) chord	DC	WWH
57	OCCOCA	Occipital chord/arc ratio	*	
58	OCNINA	Opisthocranion-inion arc	T	
59	OCNINC	Opisthocranion-inion chord	DC	
60	OIX	Lambda-opisthion/inion-opisthion chord ratio	*	
61	PAA	Parietal (bregma-lambda) arc	T	
62	PAC	Parietal (bregma-lambda) chord	DC	WWH
73	SCB	Bisupramastoid crest breadth	SC	
74	SCBGOL	Bisupramastoid crest breadth/glabella-opisthocranion length ratio	*	
75	SCXCB	Bisupramastoid crest breadth/maximum biparietal breadth ratio	*	
76	SPB	Staphylion-basion length	DC	
77	SPHO	Staphylion-hormion length	DC,(D)	
78	SPOP	Staphylion-opisthion length	DC	
88	WCB	Minimum cranial breadth	DC	WWH
89	XCB	Maximum biparietal breadth	SC	RM(8(1))
90	ZYB	Bizygomatic breadth	DC2	WWH

TABLE A.4.10 FORMULAE FOR CALCULATED VARIABLES

CALCULATED VARIABLE	FORMULA	DIAGRAM
Indent of the tympanic lateral rim,	TIND = (AUBEAM - BIEAM)/2	Fig.M.5,6
Separation of endinion and inion,	ENIN = ENOP - INOP	Figs.M.4,11
Posteriority of f. magnum centre,	FPOS = (0.05 x FML) - BANT	Fig.M.5
Petrous-tympanic angle,	PTANG = 180 + PANGS - TANGS	Fig.M.7
Nasal width/height ratio,	NIDX = 100 x NLB/NLH	
Glenoid fossa length/width ratio,	GFIDX = 100 x GAP/GML	Fig.M.6
Lower/Upper cranial breadth ratio,	SCBXCB = 100 x SCB/XCB	Fig.M.10
Cranial breadth/length ratio,	SCBGOL = 100 x SCB/GOL	
Occipital chord/arc ratio,	OCCOCA = 100 x OCC/OCA	Fig.M.1
Occipital index,	OIX = LINC/INOPC	Fig.M.1
Angle of base flexion,	BANG = 180 x [ACOS(HV/SPHO)+ACOS(HV/BHO)]/PI	Fig.M.4
Angle of inclination of f.magnum,	FANG = 180 x [ACOS(BV/SPB)+ ACOS(BV/FML)]/PI	Fig.M.4
Mastoid Process Volume,	MPV = $\sqrt[3]{}$/(MPL x MPD x MPW)	Figs.M.2,6
Glenoid Fossa Volume,	GFV = $\sqrt[3]{}$/(GAP x GML x GFD)	Figs.3,6
Nasal Area,	NLA = 0.05 x NLB $\sqrt{}$/[(NLH)^2- (0.05 NLB)^2]	
*Glenoid Fossa Area,	GFA = $\sqrt{}$/[(GL1+GL2+GL3)x(GL1-GL2+GL3) x(GL1+GL2-GL3)x(GL2+GL3-GL1)/16]	Fig.M.6

* Hinton & Carlson, 1979:327

TABLE A.4.11 PRECISION ESTIMATORS & VARIABLE MEANS.

With a sample of 12 crania, 66 direct measurements were taken and 24 derived* variables calculated. With a sample of 7 crania, 2 further direct measurements** were taken.

	VARIABLE		AV.MEAN	MEAN 2	MEAN 1	SD	TEM	CV	%ERR	t-VAL	p_t
1	ASB		106.308	106.383	106.346	.373	.264	.248	.259	- .68	.510
2	ATANGSL		83.250	83.792	83.521	2.324	1.636	1.959	2.444	- .80	.441
3	ATANGSR		82.583	84.167	83.375	3.434	2.428	2.912	2.998	-1.72	.113
4	ATANGLR*		165.833	167.958	166.896	4.985	3.525	2.112	2.272	-1.56	.146
5	AUB		117.475	117.533	117.504	.155	.110	.094	.092	-1.34	.206
6	AUBEAM		117.617	117.625	117.621	.161	.117	.097	.106	- .17	.870
7	BANG	*	105.613	105.079	105.346	2.542	1.797	1.706	1.889	.71	.490
8	BANT		4.442	4.192	4.317	.694	.491	11.369	11.583	1.28	.227
9	BBH		134.267	134.108	134.188	.699	.495	.369	.329	.77	.457
10	BHO		28.558	29.233	28.896	1.016	.719	2.487	2.797	-2.95	.013
11	BIEAM		103.146	103.067	103.106	.332	.232	.228	.222	.82	.427
12	BV		3.458	3.317	3.388	.465	.329	9.698	10.578	1.06	.311
13	EANGL		51.133	51.083	51.108	1.652	1.168	2.286	2.707	.10	.922
14	EDIAML		9.292	9.617	9.454	.645	.456	4.823	5.729	-1.94	.079
15	ELANGL		58.292	58.083	58.188	2.471	1.747	3.002	3.366	.28	.784
16	ENIN		4.025	2.598	3.312	2.219	1.639	49.483	51.635	2.59	.025
17	ENOP		43.417	42.550	42.983	1.716	1.213	1.165	1.360	1.94	.078
18	EUANGL		41.810	42.130	41.970	3.187	2.158	5.140	5.459	- .32	.758
19	FANG	*	168.243	170.561	169.402	3.439	2.432	1.435	1.484	-3.03	.012
20	FMB		29.967	29.958	29.963	.222	.157	.523	.528	.12	.903
21	FML		36.867	36.833	36.850	.300	.212	.576	.678	.37	.718
22	FPOS	*	14.004	14.233	14.119	.692	.490	3.468	3.453	-1.16	.269
23	FRA		126.083	125.708	125.896	.692	.489	.389	.364	2.14	.056
24	FRC		110.983	110.942	110.962	.325	.230	.207	.218	.43	.677
25	GAPL		17.113	17.558	17.335	.707	.500	2.882	3.437	-2.70	.021
26	GFAL	*	144.367	149.192	146.779	7.797	5.513	3.756	4.309	-2.61	.024
27	GFDL		5.787	6.067	5.927	.405	.287	4.837	5.272	-3.15	.009
28	GFIDXL	*	72.855	73.908	73.382	3.711	2.741	3.735	4.345	- .94	.369
29	GL1L		25.017	25.233	25.125	.528	.373	1.485	1.725	-1.49	.163
30	GL2L		17.242	17.742	17.492	.775	.548	3.131	3.049	-2.80	.017
31	GL3L		16.858	16.875	16.867	.410	.290	1.720	1.779	- .13	.895
32	GFVL	*	13.229	13.612	13.420	.482	.356	2.652	2.985	-3.96	.002
33	GMLL		23.567	23.817	23.692	.860	.608	2.567	2.884	-1.01	.335
34	GOL		180.042	179.992	180.017	.178	.126	.070	.083	.97	.352
35	HOV		17.492	17.617	17.554	.530	.375	2.135	2.516	- .81	.438
36	INOPC		39.392	39.217	39.304	.766	.542	1.379	1.505	.78	.453
37	LINC		66.333	66.500	66.417	.752	.532	.800	.853	- .75	.467
38	MANGL		64.708	65.625	65.167	2.273	1.607	2.466	2.558	-1.46	.172
39	MPDAV	*	13.279	13.125	13.202	.274	.192	1.469	1.799	2.25	.046
40	MPDL		13.008	12.958	12.983	.314	.222	1.708	1.926	.54	.603
41	MPDR		13.550	13.250	13.400	.488	.345	2.576	2.985	2.58	.025
42	MPLL		32.933	32.825	32.879	.863	.610	1.855	2.000	.42	.683
43	MPVAV	*	21.619	20.821	21.220	.618	.702	3.308	3.899	4.47	.001
44	MPVL	*	21.331	20.627	20.979	.694	.685	3.263	4.003	3.52	.005
45	MPWAV	*	23.254	21.092	22.173	3.041	2.150	9.697	10.670	3.36	.006
46	MPWL		22.817	20.775	21.796	3.080	2.178	9.992	11.430	2.94	.014
47	MPWR		23.683	21.375	22.529	3.236	2.288	10.156	10.760	3.38	.006

TABLE A.4.11
PRECISION ESTIMATORS & VARIABLE MEANS (Contd.)

* derived variable; ** these 2 measurements involved a different sample of 7 crania.

NO.	VARIABLE	AV.MEAN	MEAN 2	MEAN 1	SD	TEM	CV	%ERR	t-VAL	p_1
48	MSCANGL*	53.750	54.667	54.208	3.819	2.700	4.981	5.534	- .82	.430
49	NLA	27.662	27.853	27.758	.348	.236	.849	.897	-2.32	.041
50	NBHX *	49.278	49.412	49.345	.580	.393	.796	.832	.82	.429
51	NLB	24.908	25.033	24.971	.266	.188	.754	.701	-1.76	.105
52	NLHAV *	50.900	51.000	50.950	.245	.173	.340	.393	-1.48	.166
53	NLHL	50.725	50.867	50.796	.236	.167	.329	.410	-2.48	.030
54	NLHR	51.075	51.150	51.113	.364	.257	.504	.571	- .70	.499
55	NOL	77.508	177.358	177.433	.416	.294	.166	.169	1.28	.227
56	OCA	113.583	113.333	113.458	.764	.540	.476	.514	1.15	.275
57	OCC	95.558	95.600	95.579	.293	.207	.217	.218	- .48	.643
58	OCNINA	41.917	42.125	42.021	.750	.530	1.260	1.487	- .96	.358
59	OCNINC	39.558	39.583	39.571	.661	.468	1.182	1.411	- .13	.902
60	OIX *	172.125	173.192	172.658	3.700	2.616	1.515	1.448	-1.00	.339
61	PAA	124.083	124.125	124.104	.777	.550	.443	.436	- .18	.862
62	PAC	111.417	111.542	111.479	.371	.262	.235	.247	-1.19	.260
63	PANGSL	45.042	46.125	45.583	2.533	1.791	3.929	4.022	-1.57	.145
64	PANGSR	45.375	46.708	46.042	2.598	1.837	3.990	3.620	-1.98	.073
65	PANGSLR*	90.417	92.833	91.625	4.397	3.109	3.393	3.820	-2.18	.052
66	PPLAV *	31.571	31.471	31.521	.512	.293	.934	1.077	.68	.513
67	PPLL	31.842	31.717	31.779	.766	.531	1.695	1.942	.55	.591
68	PPLR	31.300	31.225	31.263	.450	.318	1.018	1.146	.56	.586
69	PTANGL *	160.792	161.792	161.292	2.677	1.893	1.174	1.395	-1.34	.209
70	PTANGR *	162.167	161.917	162.042	2.318	1.639	1.012	1.234	.36	.726
71	SCANGL	10.958	10.958	10.958	2.685	1.898	17.324	20.532	.00	1.000
72	SCB	127.808	127.750	127.779	.384	.272	.213	.202	.51	.620
73	SCB/GOL*	70.982	70.966	70.974	.232	.157	.222	.253	.23	.823
74	SCB/XCB*	96.167	96.158	96.163	.240	.170	.176	.199	.12	.910
75	SPB	46.042	45.925	45.983	.412	.292	.634	.725	.98	.349
76	SPHO	29.575	29.017	29.296	.886	.626	2.137	2.190	2.69	.021
77	SPOP	82.342	82.192	82.267	.396	.280	.340	.385	1.36	.202
78	TANGSL	64.250	64.333	64.292	1.732	1.225	1.905	2.204	-.16	.876
79	TANGSR	63.208	64.792	64.000	2.198	1.555	2.429	2.604	-3.44	.005
80	TANGSLR*	127.458	129.125	128.292	2.677	1.893	1.476	1.559	-2.64	.023
81	TIND *	7.237	7.250	7.244	.151	.107	1.471	1.783	- .28	.788
82	TPHL	17.083	17.208	17.146	.441	.312	1.817	1.896	- .98	.348
83	TPLL	26.808	26.650	26.729	1.272	.900	3.366	3.336	.42	.685
84	TSQHL	45.167	44.992	45.079	1.088	.769	1.707	1.867	.54	.600
85	TTHKAV *	3.092	3.179	3.135	.311	.220	7.004	7.575	- .97	.351
86	TTHKL	3.058	3.167	3.113	.475	.336	10.796	10.442	- .78	.454
87	TTHKR	3.117	3.175	3.146	.206	.146	4.634	4.503	- .98	.349
88	WCB	68.983	69.750	69.367	2.300	1.626	2.344	1.898	-1.17	.266
89	XCB	133.233	133.175	133.204	.312	.221	.166	.181	.63	.541
90	ZYB	130.108	130.083	130.096	.119	.084	.065	.071	.71	.491
91	PIANGTL**	77.036	76.429	77.643	2.177	1.66	2.160	1.571	1.48	.190
92	PIANGTR**	77.750	77.214	78.286	4.257	2.89	3.714	1.376	.67	.530

TABLE A.4.12. PRECISION ESTIMATOR VALUES

90 Variables, 3 precision estimator values in descending order of magnitude. (* derived variable, ** 7 cases only)

(i) NO.	VARIABLE	p	t-VAL	(ii) NO.	VARIABLE		TEM	(iii) NO.	VARIABLE		%ERR
43	MPVAV	*.001	4.47	26	GFAL	*	5.513	16	ENIN	*	51.635
32	GFVL	*.002	-3.96	4	ATANGLR		3.525	71	SCANGL		20.532
44	MPVL	*.005	3.52	65	PANGSLR		3.109	8	BANT		11.583
79	TANGSR	.005	-3.44	*92*	*PIANGTR*	**	*2.888*	46	MPWL		11.430
47	MPWR	.006	3.38	28	GFIDXL	*	2.741	47	MPWR		10.760
45	MPWAV	*.006	3.36	48	MSCANGL	*	2.700	45	MPWAV	*	10.670
27	GFDL	.009	-3.15	60	OIX	*	2.616	12	BV		10.578
19	FANG	*.012	-3.03	19	FANG	*	2.432	86	TTHKL		10.442
10	BHO	.013	-2.95	3	ATANGSR		2.428	85	TTHKAV	*	7.575
46	MPWL	.014	2.94	47	MPWR		2.288	14	EDIAML		5.729
30	GL2L	.017	-2.80	46	MPWL		2.178	48	MSCANGL	*	5.534
25	GAPL	.021	-2.70	18	EUANGL		2.158	18	EUANGL		5.459
76	SPHO	.021	2.69	45	MPWAV	*	2.150	27	GFDL		5.272
80	TANGSLR	*.023	-2.64	71	SCANGL		1.898	87	TTHKR		4.503
26	GFAL	*.024	-2.61	69	PTANGL	*	1.893	28	GFIDXL	*	4.345
16	ENIN	*.025	2.59	80	TANGSLR	*	1.893	26	GFAL	*	4.309
41	MPDR	.025	2.58	64	PANGSR		1.837	63	PANGSL		4.022
53	NLHL	.030	-2.48	7	BANG	*	1.797	44	MPVL	*	4.003
49	NLA	*.041	-2.32	63	PANGSL		1.791	43	MPVAV	*	3.899
39	MPDAV	*.046	2.25	15	ELANGL		1.747	65	PANGSLR	*	3.820
65	PANGSLR	*.052	-2.18	*91*	*PIANGTL*	**	*1.664*	64	PANGSR		3.620
23	FRA	.056	2.14	70	PTANGR	*	1.639	22	FPOS	*	3.453
64	PANGSR	.073	-1.98	16	ENIN	*	1.639	25	GAPL		3.437
17	ENOP	.078	1.94	2	ATANGSL		1.636	15	ELANGL		3.366
14	EDIAML	.079	-1.94	88	WCB		1.626	83	TPLL		3.336
51	NLB	.105	-1.76	38	MANGL		1.607	30	GL2L		3.049
3	ATANGSR	.113	-1.72	79	TANGSR		1.555	3	ATANGSR		2.998
63	PANGSL	.145	-1.57	78	TANGSL		1.225	32	GFVL	*	2.985
4	ATANGLR	.146	-1.56	17	ENOP		1.213	41	MPDR		2.985
29	GL1L	.163	-1.49	13	EANGL		1.168	33	GMLL		2.884
52	NLHAV	*.166	-1.48	83	TPLL		.900	10	BHO		2.797
91	*PIANGTL*	*.190	*1.48*	84	TSQHL		.769	13	EANGL		2.707
38	MANGL	.172	-1.46	10	BHO		.719	79	TANGSR		2.604
77	SPOP	.202	1.36	43	MPVAV	*	.702	38	MANGL		2.558
5	AUB	.206	-1.34	44	MPVL	*	.685	35	HOV		2.516
69	PTANGL	*.209	-1.34	76	SPHO		.626	2	ATANGSL		2.444
8	BANT	.227	1.28	42	MPLL		.610	4	ATANGLR	*	2.272
55	NOL	.227	1.28	33	GMLL		.608	78	TANGSL		2.204
62	PAC	.260	-1.19	61	PAA		.550	76	SPHO		2.190
88	WCB	.266	-1.17	30	GL2L		.548	42	MPLL		2.000
22	FPOS	*.269	-1.16	36	INOPC		.542	67	PPLL		1.942
56	OCA	.275	1.15	56	OCA		.540	40	MPDL		1.926
12	BV	.311	1.06	37	LINC		.532	88	WCB		1.898
33	GMLL	.335	-1.01	67	PPLL		.531	82	TPHL		1.896
60	OIX	*.339	-1.00	58	OCNINA		.530	7	BANG	*	1.889
82	TPHL	.348	-.98	25	GAPL		.500	84	TSQHL		1.867

TABLE A.4.12 PRECISION ESTIMATOR VALUES (contd.)

(* derived variable)

(i) NO.	VARIABLE		p	t-VAL	(ii) NO.	VARIABLE		TEM	(iii) NO.	VARIABLE		%ERR
87	TTHKR		.349	-.98	9	BBH		.495	39	MPDAV	*	1.799
75	SPB		.349	.98	8	BANT		.491	81	TIND	*	1.783
85	TTHKAV	*	.351	-.97	22	FPOS	*	.490	31	GL3L		1.779
34	GOL		.352	.97	23	FRA		.489	29	GL1L		1.725
58	OCNINA		.358	-.96	59	OCNINC		.468	91	PIANGTL	#	1.571
28	GFIDX	*	.369	-.94	14	EDIAML		.456	80	TANGSLR	*	1.559
11	BIEAM		.427	.82	50	NBHX	*	.393	36	INOPC		1.505
50	NBHX	*	.429	.82	35	HOV		.375	58	OCNINA		1.487
48	MSCANGL	*	.430	-.82	29	GL1L		.373	19	FANG	*	1.484
35	HOV		.438	-.81	32	GFVL	*	.356	60	OIX	*	1.448
2	ATANGSL		.441	-.80	41	MPDR		.345	59	OCNINC		1.411
36	INOPC		.453	.78	86	TTHKL		.336	69	PTANGL	*	1.395
86	TTHKL		.454	-.78	12	BV		.329	*92*	*PIANGTR*	**	*1.376*
9	BBH		.457	.77	68	PPLR		.318	17	ENOP		1.360
37	LINC		.467	-.75	82	TPHL		.312	70	PTANGR	*	1.234
7	BANG	*	.490	.71	55	NOL		.294	68	PPLR		1.146
90	ZYB		.491	.71	66	PPLAV	*	.293	66	PPLAV	*	1.077
54	NLHR		.499	-.70	75	SPB		.292	49	NLA	*	.897
1	ASB		.510	-.68	31	GL3L		.290	37	LINC		.853
66	PPLAV	*	.513	.68	27	GFDL		.287	50	NBHX	*	.832
92	*PIANGTR*	**	*.530*	*.67*	77	SPOP		.280	75	SPB		.725
89	XCB		.541	.63	72	SCB		.272	51	NLB		.701
68	PPLR		.586	.56	1	ASB		.264	21	FML		.678
67	PPLL		.591	.55	62	PAC		.262	54	NLHR		.571
84	TSQHL		.600	.54	54	NLHR		.257	20	FMB		.528
40	MPDL		.603	.54	49	NLA	*	.236	56	OCA		.514
72	SCB		.620	.51	11	BIEAM		.232	61	PAA		.436
57	OCC		.643	-.48	24	FRC		.230	53	NLHL		.410
24	FRC		.677	.43	40	MPDL		.222	52	NLHAV	*	.393
42	MPLL		.683	.42	89	XCB		.221	77	SPOP		.385
83	TPLL		.685	.42	85	TTHKAV	*	.220	23	FRA		.364
21	FML		.718	.37	21	FML		.212	9	BBH		.329
70	PTANGR	*	.726	.36	57	OCC		.207	1	ASB		.259
18	EUANGL		.758	-.32	39	MPDAV	*	.192	73	SCB/GOL	*	.253
15	ELANGL		.784	.28	51	NLB		.188	62	PAC		.247
81	TIND	*	.788	-.28	52	NLHAV	*	.173	11	BIEAM		.222
73	SCB/GOL	*	.823	.23	74	SCB/XCB	*	.170	24	FRC		.218
61	PAA		.862	-.18	53	NLHL		.167	57	OCC		.218
6	AUBEAM		.870	-.17	73	SCB/GOL	*	.157	72	SCB		.202
78	TANGSL		.876	-.16	20	FMB		.157	74	SCB/XCB	*	.199
31	GL3L		.895	-.13	87	TTHKR		.146	89	XCB		.181
59	OCNINC		.902	-.13	34	GOL		.126	55	NOL		.169
20	FMB		.903	.12	6	AUBEAM		.117	6	AUBEAM		.106
74	SCB/XCB	*	.910	.12	5	AUB		.110	5	AUB		.092
13	EANGL		.922	.10	81	TIND	*	.107	34	GOL		.083
71	SCANGL		1.000	.00	90	ZYB		.084	90	ZYB		.071

TABLE A.4.13 BILATERAL ASYMMETRY

33 VARIABLES (16 direct & 4 derived* linear, 12 direct & 1 derived* angular). (i) SMALL SAMPLE (12 to 14 SPECIMENS), 33 VARIABLES;
(ii) LARGER SAMPLE (49 to 443 SPECIMENS), 24 VARIABLES.

VARIABLE	Side	No.	Mean	St.Dev.	CV	t-Value	2tProb.	CORR.	2tProb
1. Mastoid Depth	L	12	13.01	1.98		-2.75	.019	.948	.000
	R	12	13.55	2.13					
	L	439	12.23	2.06	8.78	-2.78	.006	.878	.000
R>L	R	439	12.37	2.23					
2. Mastoid Width	L	12	22.82	4.50		-2.15	.055	.952	.000
	R	12	23.68	4.53					
	L	436	19.40	3.70	5.23	-5.53	.000	.929	.000
R>L	R	436	19.77	3.76					
3. Mastoid Length	L	12	32.93	5.47		-0.87	.402	.961	.000
	R	12	33.32	5.13					
	L	83	28.66	4.00	3.84	-3.01	.003	.934	.000
R>L	R	83	29.16	4.20					
4. *Mastoid Volume	L	12	21.33	3.37		-2.85	.016	.972	.000
	R	12	21.98	3.35					
	L	80	17.81	2.48	3.96	-2.82	.006	.933	.000
R>L	R	80	18.11	2.67					
5. Temporal Squamous Height	L	12	45.17	6.16		1.47	.171	.975	.000
	R	12	44.58	6.06					
	L	88	45.68	6.25	2.83	1.50	.137	.958	.000
	R	88	45.39	6.29					
6. Ex.Aud. Meatus Max. Diameter	L	12	9.29	0.80		1.18	.262	.957	.000
	R	12	9.21	0.85					
	L	95	9.13	1.01	5.85	1.09	.277	.703	.000
	R	95	9.05	.93					
7. Tymanic Plate Rim Thickness	L	12	3.06	1.47		-0.57	.578	.973	.000
	R	12	3.12	1.34					
	L	423	2.72	1.24	12.73	-3.50	.001	.922	.000
R>L	R	423	2.81	1.25					
8. Tympanic Plate Length	L	12	26.81	3.48		0.62	.547	.973	.000
	R	12	26.65	3.02					
	L	152	26.59	3.03	2.99	0.66	.508	.929	.000
	R	152	26.53	2.89					

TABLE A.4.13 BILATERAL ASYMMETRY (Continued)

VARIABLE	Side	No.	Mean	St.Dev.	CV	t-Value	2tProb.	CORR.	2tProb
9. Tympanic Plate Height L>R	L	12	17.08	1.34		.73	.483	.685	.014
	R	12	16.88	1.10					
	L	194	17.17	2.12	3.55	2.15	.033	.919	.000
	R	194	17.04	2.10					
10. Petrous Pyramid Length	L	12	31.50	3.26		.73	.480	.932	.000
	R	12	31.25	2.98					
	L	426	31.79	2.30	1.81	.49	.626	.936	.000
	R	426	31.77	2.26					
11. Glenoid Fossa ant/post Lgth.	L	12	17.11	1.41		5.14	.000	.931	.000
	R	12	16.31	1.15					
	L	91	17.14	1.70	3.05	-.56	.574	.900	.000
	R	91	17.18	1.59					
12. Glenoid Fossa med/lat Width	L	12	23.57	1.80		-.39	.703	.938	.000
	R	12	23.64	1.92					
	L	90	23.25	1.82	3.17	-.64	.526	.838	.000
	R	90	23.23	1.85					
13. *Glenoid Fossa L/B Ratio	L	12	72.86	6.75		4.28	.001	.909	.000
	R	12	69.22	5.25					
	L	90	73.86	6.66	4.66	.16	.874	.701	.000
	R	90	73.78	5.34					
14. Glenoid Fossa Depth R>L	L	12	5.79	.87		-3.68	.004	.726	.008
	R	12	6.49	.92					
	L	49	5.69	.79	3.85	-2.50	.016	.927	.000
	R	49	5.80	.76					
15. *Glenoid Fossa Volume	L	12	13.23	1.01		-2.07	.063	.868	.000
	R	12	13.55	1.08					
	L	49	12.77	1.03	1.94	-1.56	.126	.943	.000
	R	49	12.84	1.00					
16.G.Fossa Length 1 L>R	L	12	25.02	2.07	1.97	2.85	.016	.965	.000
	R	12	24.57	2.08					
17.G.Fossa Length 2	L	12	17.24	1.47	4.80	.97	.354	.840	.001
	R	12	16.92	2.08					
18.G.Fossa Length 3	L	12	16.86	1.94	5.21	1.67	.123	.822	.001
	R	12	16.31	1.31					
19.*G.Foss Area L>R	L	12	144.37	22.56	17.39	3.22	.008	.929	.000
	R	12	136.59	20.21					

TABLE A.4.13 BILATERAL ASYMMETRY (Continued)

VARIABLE	Side	No.	Mean	St.Dev.	CV	t-Value	2tProb.	CORR.	2tProb
20. Petrous Angle	L	12	44.79	3.65		-1.21	.253	.888	.000
	R	12	45.38	3.30					
Sagittal R>L	L	441	45.55	4.11	3.35	-2.71	.007	.872	.000
	R	441	45.83	4.33					
21.Tymp. Plate Sag. Angle L>R	L	12	64.08	2.27		1.60	.137	.617	.032
	R	12	63.20	2.08					
	L	443	63.01	3.62	2.40	.77	.444	.825	.000
	R	443	62.93	3.63					
22. Petrous -Tymp. Angle R>L	L	12	160.71	4.41		-3.31	.007	.937	.000
	R	12	162.18	4.42					
	L	441	162.53	4.90	.91	-3.92	.000	.912	.000
	R	441	162.92	4.95					
23. Ant.Tymp. Plate Sag.Ang. R>L	L	12	83.25	8.51		1.17	.268	.975	.000
	R	12	82.58	7.73					
	L	441	79.71	5.89	2.93	-7.51	.000	.857	.000
	R	441	80.83	5.83					
24.Petrous Int.Trans. Angle	L	13	77.81	4.56	3.91	-1.39	.191	.965	.000
	R	13	79.42	6.40					
25. Mastoid Angle	L	12	64.92	9.00		-.28	.784	.784	.003
	R	12	65.38	6.31					
	L	86	71.02	7.26	5.02	-.04	.966	.734	.000
	R	86	71.04	6.53					
26. Mastoid S'meatal Crest Angle	L	12	53.92	8.77		-.10	.925	.735	.007
	R	12	54.08	7.39					
	L	86	55.33	9.02	7.43	-.30	.763	.770	.000
	R	86	55.52	8.01					
27. S'meatal Crest Angle	L	12	11.00	5.67		.00	1.000	.881	.000
	R	12	11.00	5.68					
	L	86	15.69	5.55	20.86	.34	.738	.616	.000
	R	86	15.52	4.94					
28.Lower EAM Angle	L	12	58.29	6.81	6.07	-1.00	.340	.685	.014
	R	12	59.75	5.71					
29.Upper EAM Angle	L	12	41.59	6.80	9.71	.57	.582	.624	.040
	R	12	40.59	6.63					
30. Central EAM Angle R>L	L	12	50.96	6.48		.06	.951	.712	.009
	R	12	50.88	5.06					
	L	89	49.23	5.80	9.97	-5.92	.000	.579	.000
	R	89	53.08	7.43					
31. Nasal Height	L	12	50.73	5.87		-.99	.346	.980	.000
	R	12	51.08	6.10					
	L	441	48.81	4.16	1.38	-.36	.719	.974	.000
	R	441	48.82	4.16					

TABLE A.5.1. MEANS, STANDARD DEVIATION

26 TEMPORAL VARIABLES, 11 MODERN HUMAN POPULATIONS

	Mean	Std Dev	Cases	GRP		Mean	Std Dev	Cases
ATANGS	79.72	5.90	445	TOT	BANT	5.463	2.277	443
	77.81	5.75	50	AND		5.036	1.827	50
	79.47	4.66	76	AUS		5.662	2.082	76
	81.74	5.43	21	BUS		3.940	2.044	20
	75.11	4.45	50	CHI		5.118	2.197	50
	85.44	5.67	52	ESK		6.367	2.069	52
	78.22	6.34	16	FUE		5.656	2.089	16
	82.77	5.96	50	GAB		5.946	2.345	50
	78.16	5.53	49	NEW		5.642	2.264	50
	78.81	4.47	50	POU		5.078	3.148	50
	81.19	3.93	13	TAS		5.209	1.826	11
	78.64	4.23	18	VED		5.061	1.388	18
EANG	50.05	6.61	443	TOT	12.69	2.48	442	FPOS2
	49.80	6.65	50	AND		11.90	2.08	50
	49.91	6.57	76	AUS		12.07	2.24	76
	45.74	7.22	21	BUS		14.56	2.29	20
	51.47	6.48	48	CHI		13.27	2.47	50
	48.65	5.33	52	ESK		13.54	2.21	52
	50.31	5.28	16	FUE		13.06	2.28	16
	52.30	6.09	50	GAB		12.25	2.32	50
	51.27	7.46	50	NEW		11.82	2.04	50
	49.49	5.73	50	POU		13.36	3.43	50
	47.79	9.09	12	TAS		12.74	2.01	10
	49.92	7.43	18	VED		12.83	1.72	18
GAP	17.23	1.56	447	TOT	149.67	23.62	446	GFA2
	15.94	1.12	50	AND		127.54	16.17	50
	17.76	1.12	76	AUS		156.90	19.90	76
	15.66	.95	21	BUS		125.88	16.42	21
	17.27	1.65	50	CHI		156.72	19.87	50
	18.21	1.26	52	ESK		162.24	21.09	52
	19.16	1.51	16	FUE		176.23	26.70	16
	16.58	1.51	50	GAB		139.53	18.82	50
	17.68	1.29	50	NEW		157.44	20.00	50
	17.33	1.34	50	POU		149.61	23.89	50
	17.69	1.03	14	TAS		149.89	15.99	13
	15.61	1.27	18	VED		135.36	17.90	18
GFD	6.243	1.099	447	TOT	GFIDX	72.86	6.06	447
	5.602	.870	50	AND		70.89	4.16	50
	6.271	.921	76	AUS		72.90	5.48	76
	5.581	1.569	21	BUS		73.54	5.94	21
	6.906	.957	50	CHI		71.26	7.38	50
	5.979	1.020	52	ESK		76.64	7.07	52
	6.106	1.217	16	FUE		74.29	3.62	16
	6.112	1.026	50	GAB		72.72	6.11	50
	5.962	.876	50	NEW		74.76	5.38	50
	7.131	1.022	50	POU		70.76	5.58	50
	6.357	.735	14	TAS		73.60	4.76	14
	6.317	1.119	18	VED		70.05	4.95	18
GFV	13.61	1.26	447	TOT	GML	23.71	1.98	447
	12.59	1.00	50	AND		22.51	1.44	50
	13.93	.98	76	AUS		24.45	1.87	76
	12.22	1.43	21	BUS		21.39	1.72	21
	14.23	1.14	50	CHI		24.31	1.71	50
	13.70	1.07	52	ESK		23.87	1.81	52
	14.39	1.39	16	FUE		25.79	1.50	16
	13.19	1.14	50	GAB		22.86	1.71	50
	13.54	1.07	50	NEW		23.72	1.75	50
	14.45	1.17	50	POU		24.58	2.01	50
	13.92	.81	14	TAS		24.08	1.43	14
	12.97	1.18	18	VED		22.32	1.50	18

TABLE A.5.1. MEANS, STANDARD DEVIATION (Contd.)

26 TEMPORAL, 11 MODERN HUMAN POPULATIONS

	Mean	Std Dev	Cases	GRP
MANG	68.10	6.37	446	TOT
	73.20	5.32	50	AND
	64.54	5.06	76	AUS
	64.60	6.21	21	BUS
	70.22	6.12	50	CHI
	67.33	7.85	52	ESK
	68.78	4.73	16	FUE
	69.66	6.19	50	GAB
	67.69	5.79	50	NEW
	66.85	5.44	50	POU
	69.08	5.00	13	TAS
	68.36	4.86	18	VED
MPL	30.73	4.37	444	TOT
	27.53	2.60	50	AND
	32.52	4.10	76	AUS
	28.02	4.18	21	BUS
	32.39	3.60	50	CHI
	29.81	4.48	51	ESK
	34.18	3.13	16	FUE
	29.73	3.40	50	GAB
	30.81	4.20	50	NEW
	33.41	3.84	50	POU
	24.92	2.80	12	TAS
	29.10	4.56	18	VED
MPW	19.31	3.70	447	TOT
	16.71	2.55	50	AND
	18.85	3.15	76	AUS
	17.75	2.35	21	BUS
	22.08	3.11	50	CHI
	17.85	3.19	52	ESK
	24.38	3.02	16	FUE
	18.02	2.81	50	GAB
	19.52	2.62	50	NEW
	22.53	3.93	50	POU
	16.61	2.60	14	TAS
	18.57	3.38	18	VED
PANGS	45.58	4.11	445	TOT
	46.67	3.43	50	AND
	43.63	3.90	76	AUS
	43.88	3.80	20	BUS
	46.80	2.57	50	CHI
	48.33	4.34	52	ESK
	44.72	2.26	16	FUE
	42.34	3.83	50	GAB
	45.37	2.94	50	NEW
	46.84	4.67	50	POU
	48.81	3.17	13	TAS
	45.83	3.23	18	VED
PTANG	162.51	4.90	444	TOT
	163.49	4.48	50	AND
	160.17	4.62	76	AUS
	159.38	5.16	20	BUS
	164.64	5.04	50	CHI
	162.69	4.96	51	ESK
	160.34	2.82	16	FUE
	161.07	5.20	50	GAB
	162.73	3.79	50	NEW
	164.47	4.20	50	POU
	164.54	5.27	13	TAS
	165.17	4.25	18	VED

	Mean	Std Dev	Cases
MPD	12.31	2.07	446
	11.25	1.57	50
	12.91	1.53	76
	11.55	2.25	21
	12.78	1.97	50
	12.27	2.04	52
	13.59	1.56	16
	10.92	2.02	49
	13.28	2.24	50
	12.85	1.85	50
	11.77	1.81	14
	11.35	2.39	18
MPV	19.41	2.78	443
	17.35	1.79	50
	19.91	2.31	76
	17.94	2.32	21
	20.86	2.22	50
	18.77	2.83	51
	22.44	2.03	16
	17.96	2.26	49
	19.97	2.57	50
	21.37	2.62	50
	17.00	2.14	12
	18.33	2.98	18
MSCANG	55.60	7.39	446
	60.74	6.33	50
	55.49	5.65	76
	53.48	6.35	21
	56.30	6.14	50
	48.49	7.63	52
	53.16	6.39	16
	57.74	7.55	50
	53.41	7.42	50
	58.51	6.65	50
	53.85	5.33	13
	58.42	5.28	18
PPL	31.80	2.29	447
	29.94	1.90	50
	31.69	1.96	76
	32.32	1.71	21
	33.04	2.11	50
	32.62	2.23	52
	32.63	2.52	16
	32.45	2.21	50
	30.73	1.77	50
	32.46	2.26	50
	29.54	1.70	14
	31.23	2.37	18
SCANG	12.54	5.10	446
	12.46	4.15	50
	9.32	3.43	76
	11.14	3.34	21
	13.92	3.67	50
	18.83	5.38	52
	15.63	4.07	16
	11.93	4.16	50
	14.26	4.13	50
	8.34	4.05	50
	15.23	3.08	13
	9.94	3.71	18

TABLE A.5.1. MEANS, STANDARD DEVIATION (Contd.)

26 TEMPORAL VARIABLES, 11 MODERN HUMAN POPULATIONS

	Mean	Std Dev	Cases	GRP		Mean	Std Dev	Cases
TANGS	63.04	3.63	446	TOT	TIND	7.480	1.654	447
	63.11	3.29	50	AND		8.024	1.374	50
	63.47	2.99	76	AUS		6.855	1.381	76
	64.40	3.38	21	BUS		7.624	1.597	21
	62.15	3.92	50	CHI		8.274	1.294	50
	65.56	3.75	52	ESK		7.068	1.570	52
	64.38	2.54	16	FUE		9.250	1.584	16
	61.23	3.84	50	GAB		6.152	1.532	50
	62.62	2.96	50	NEW		7.848	1.615	50
	62.37	3.93	50	POU		8.008	1.375	50
	64.27	3.03	13	TAS		8.414	1.527	14
	60.67	2.26	18	VED		6.333	1.581	18
TPH	16.84	1.98	447	TOT	TPL	26.75	2.75	447
	15.22	1.47	50	AND		24.87	2.07	50
	16.13	1.74	76	AUS		27.35	2.55	76
	16.43	1.63	21	BUS		24.70	2.24	21
	18.77	1.75	50	CHI		27.20	2.83	50
	17.03	1.73	52	ESK		27.79	2.67	52
	17.44	2.10	16	FUE		30.85	2.52	16
	17.21	1.68	50	GAB		27.07	1.98	50
	16.74	1.39	50	NEW		26.30	2.67	50
	17.98	1.96	50	POU		26.62	2.42	50
	14.76	.92	14	TAS		26.52	1.53	14
	16.08	1.81	18	VED		24.91	3.03	18
TSQH	44.99	5.18	445	TOT	TTHK	2.727	1.203	447
	41.42	4.12	50	AND		1.522	.466	50
	43.45	4.07	76	AUS		3.201	1.014	76
	39.51	4.00	21	BUS		2.181	.691	21
	48.42	3.29	50	CHI		2.365	.788	50
	49.86	5.34	51	ESK		4.720	1.037	52
	47.24	4.01	16	FUE		2.913	1.143	16
	43.88	4.32	50	GAB		2.331	.730	50
	45.64	4.24	50	NEW		2.217	.674	50
	47.05	3.90	50	POU		2.725	.924	50
	38.42	4.67	13	TAS		2.325	.745	14
	42.70	3.62	18	VED		2.622	.869	18

TABLE A.5.1. MEANS, STANDARD DEVIATION (Contd.)

29 NON-TEMPORAL VARIABLES, 11 MODERN HUMAN POPULATIONS

	Mean	Std Dev	Cases	GRP		Mean	Std Dev	Cases
ASB	105.34	6.08	445	TOT	AUB	117.73	7.40	446
	97.72	4.29	50	AND		110.92	3.96	50
	105.59	4.54	76	AUS		116.20	5.31	76
	105.92	3.57	21	BUS		110.31	4.57	21
	106.57	4.95	50	CHI		122.82	5.15	50
	108.08	4.92	52	ESK		124.00	5.34	52
	109.76	3.13	16	FUE		129.66	5.24	16
	103.01	4.63	50	GAB		112.62	5.11	50
	105.03	4.37	50	NEW		117.76	5.32	50
	111.54	6.67	50	POU		121.72	6.87	50
	105.28	4.14	12	TAS		119.29	4.07	13
	99.69	4.25	18	VED		110.90	5.48	18
BANG	108.50	8.40	443	TOT	BBH	132.44	6.63	445
	107.95	7.47	50	AND		127.52	5.77	50
	109.31	7.80	76	AUS		132.38	6.29	76
	112.92	8.93	20	BUS		125.95	4.50	21
	104.53	8.07	50	CHI		135.44	5.82	50
	108.90	6.50	52	ESK		136.75	5.58	52
	106.12	6.74	16	FUE		137.57	6.37	16
	113.49	7.29	50	GAB		133.48	6.12	50
	112.66	6.32	50	NEW		132.74	5.10	50
	99.54	7.72	50	POU		131.38	7.11	50
	110.15	4.75	11	TAS		127.73	4.37	12
	112.27	7.31	18	VED		130.89	5.51	18
ENIN	2.513	5.583	445	TOT	ENOP	40.55	3.94	444
	7.418	5.844	50	AND		41.72	4.64	50
	2.267	5.092	76	AUS		40.31	3.67	76
	5.329	5.658	21	BUS		39.34	4.89	21
	1.388	5.344	50	CHI		40.25	3.51	50
	.712	4.632	52	ESK		40.23	3.55	52
	-.881	5.937	16	FUE		41.02	4.25	16
	4.088	5.195	50	GAB		40.56	3.86	50
	2.628	5.118	50	NEW		41.23	3.62	50
	-.310	4.265	50	POU		40.18	4.18	50
	-.058	4.125	12	TAS		40.75	2.33	11
	2.861	5.320	18	VED		40.09	4.70	18
FANG	169.62	8.10	442	TOT	FMB	29.24	2.24	445
	171.95	6.01	50	AND		27.82	1.52	50
	168.04	7.87	76	AUS		29.54	2.19	76
	170.26	6.91	20	BUS		28.51	2.21	21
	167.15	9.35	50	CHI		29.48	2.02	50
	167.44	6.64	52	ESK		30.69	1.97	52
	170.69	6.31	16	FUE		30.61	2.47	16
	176.74	6.94	50	GAB		28.94	2.47	50
	169.00	7.01	50	NEW		28.59	1.93	50
	165.34	8.89	50	POU		29.66	2.22	50
	169.36	6.70	10	TAS		28.78	2.04	12
	175.36	4.21	18	VED		28.43	2.37	18
FML	36.30	2.89	443	TOT	FRA	125.31	7.36	447
	33.81	2.17	50	AND		118.40	6.27	50
	35.46	2.30	76	AUS		127.76	7.02	76
	36.98	2.31	20	BUS		127.93	6.43	21
	36.75	2.19	50	CHI		124.35	6.21	50
	39.76	2.61	52	ESK		129.59	5.95	52
	37.39	2.63	16	FUE		128.34	5.96	16
	36.34	2.97	50	GAB		123.56	6.71	50
	34.88	2.14	50	NEW		121.44	6.64	50
	36.91	2.67	50	POU		128.52	6.92	50
	36.64	2.99	11	TAS		123.25	5.51	14
	35.77	1.61	18	VED		126.94	6.51	18

TABLE A.5.1. MEANS, STANDARD DEVIATION (Contd.)

29 NON-TEMPORAL VARIABLES, 11 MODERN HUMAN POPULATIONS

	Mean	Std Dev	Cases	GRP		Mean	Std Dev	Cases
GOL	179.31	9.62	446	TOT	INOP	38.00	4.60	444
	164.78	5.22	50	AND		34.31	3.97	50
	183.28	7.85	76	AUS		38.04	4.56	76
	175.69	5.79	21	BUS		34.01	4.24	21
	177.55	6.99	50	CHI		38.69	4.24	50
	187.49	6.94	52	ESK		39.52	4.85	52
	186.98	7.32	16	FUE		41.90	4.37	16
	175.77	7.12	50	GAB		36.47	3.89	50
	177.68	7.61	50	NEW		38.60	3.83	50
	185.76	7.52	50	POU		40.50	4.01	50
	179.81	7.00	13	TAS		40.35	2.48	11
	177.65	6.51	18	VED		37.23	2.41	18
LINC	67.39	5.92	445	TOT	NBHX	52.33	5.97	444
	64.86	4.50	50	AND		52.10	4.20	50
	65.35	5.60	76	AUS		55.35	3.86	76
	68.36	5.72	21	BUS		58.33	5.07	21
	70.75	5.40	50	CHI		50.34	3.85	50
	70.63	5.00	52	ESK		43.63	3.27	52
	71.16	7.01	16	FUE		46.91	3.25	15
	66.46	5.66	50	GAB		56.40	4.56	50
	66.69	6.31	50	NEW		55.79	3.69	50
	68.63	5.29	50	POU		48.31	3.66	50
	62.50	4.91	12	TAS		60.14	2.46	12
	64.34	4.70	18	VED		53.43	5.09	18
NLA	59.89	8.24	444	TOT	NLB	25.40	2.42	444
	51.69	4.83	50	AND		23.58	1.43	50
	64.25	6.82	76	AUS		27.16	1.75	76
	52.56	8.37	21	BUS		25.25	2.52	21
	64.30	8.08	50	CHI		25.82	2.13	50
	59.18	7.42	52	ESK		22.96	1.90	52
	62.40	6.37	15	FUE		24.49	1.45	15
	61.19	7.35	50	GAB		26.77	2.15	50
	60.56	8.00	50	NEW		26.47	2.07	50
	60.41	8.04	50	POU		24.48	2.14	50
	57.09	5.34	12	TAS		26.80	1.35	12
	55.39	5.83	18	VED		24.73	1.87	18
NLH	48.82	4.13	444	TOT	OCA	112.87	7.85	444
	45.40	2.76	50	AND		105.09	5.23	50
	49.17	3.04	76	AUS		111.74	6.60	76
	43.38	3.41	21	BUS		111.12	6.32	21
	51.36	3.25	50	CHI		116.32	7.20	50
	52.70	3.39	52	ESK		117.95	6.36	52
	52.35	3.35	15	FUE		120.91	7.87	16
	47.57	3.12	50	GAB		108.86	6.68	50
	47.52	3.39	50	NEW		112.50	7.23	50
	50.73	3.31	50	POU		118.16	6.44	50
	44.60	2.30	12	TAS		111.91	4.48	11
	46.48	3.23	18	VED		107.94	5.81	18
OCC	94.68	5.27	444	TOT	OCCOCA	84.01	2.94	444
	90.38	4.28	50	AND		86.04	1.97	50
	92.95	4.04	76	AUS		83.29	2.58	76
	91.52	5.19	21	BUS		82.41	2.91	21
	97.35	4.80	50	CHI		83.79	2.62	50
	98.21	4.06	52	ESK		83.34	2.16	52
	98.84	6.78	16	FUE		81.76	2.19	16
	95.62	5.36	50	GAB		87.88	1.83	50
	94.43	4.34	50	NEW		84.06	2.43	50
	96.13	5.07	50	POU		81.38	1.87	50
	92.25	2.67	11	TAS		82.50	2.52	11
	91.81	4.18	18	VED		85.10	2.17	18

TABLE A.5.1. MEANS, STANDARD DEVIATION (Contd.)

29 NON-TEMPORAL VARIABLES, 11 MODERN HUMAN POPULATIONS

	Mean	Std Dev	Cases	GRP		Mean	Std Dev	Cases
OCNINA	44.53	11.39	444	TOT	OIX	180.02	29.63	444
	44.84	7.88	49	AND		192.15	29.84	50
	45.17	12.06	76	AUS		175.03	30.53	76
	44.74	9.63	21	BUS		204.90	36.74	21
	46.21	13.18	50	CHI		185.38	27.55	50
	38.36	7.25	52	ESK		181.26	30.16	52
	38.31	13.68	16	FUE		171.97	26.11	16
	56.02	8.26	50	GAB		182.51	28.69	50
	38.89	9.95	50	NEW		174.43	28.04	50
	45.21	9.33	50	POU		171.41	24.10	50
	35.67	9.86	12	TAS		156.95	22.17	11
	47.11	11.15	18	VED		173.64	17.90	18
PAA	125.97	8.25	446	TOT	SCB	129.42	7.69	446
	119.28	7.05	50	AND		121.17	4.68	50
	127.55	8.04	76	AUS		127.46	5.58	76
	119.24	8.30	21	BUS		124.41	4.33	21
	127.22	7.59	50	CHI		134.10	5.24	50
	129.95	6.78	52	ESK		134.45	6.05	52
	125.19	9.01	16	FUE		139.02	4.38	16
	124.94	8.87	50	GAB		125.77	5.99	50
	127.99	7.08	50	NEW		128.73	5.92	50
	128.10	6.91	50	POU		136.64	6.88	50
	121.65	7.64	13	TAS		130.24	5.22	13
	125.94	7.14	18	VED		121.82	5.29	18
SCBGOL	72.23	3.35	445	TOT	SCBXCB	96.48	3.88	445
	73.56	2.62	50	AND		90.38	3.05	50
	69.58	2.40	76	AUS		98.18	2.54	76
	70.83	1.82	21	BUS		92.65	2.66	21
	75.61	3.64	50	CHI		96.96	2.26	50
	71.74	2.84	52	ESK		99.85	2.67	52
	74.40	2.14	16	FUE		97.72	2.37	16
	71.58	2.66	50	GAB		94.77	3.20	50
	72.50	3.12	50	NEW		98.91	2.51	50
	73.58	2.86	50	POU		96.50	2.61	50
	72.28	2.39	12	TAS		96.91	3.76	12
	68.58	2.07	18	VED		96.11	2.97	18
SPHO	29.17	2.91	444	TOT	WCB	68.34	4.35	446
	26.50	2.26	50	AND		66.22	3.86	50
	29.23	2.18	76	AUS		67.77	4.21	76
	28.58	2.92	20	BUS		67.27	4.14	21
	32.01	2.32	50	CHI		71.79	3.69	50
	29.01	2.24	52	ESK		70.75	4.33	52
	32.27	3.03	16	FUE		71.74	3.48	16
	27.22	2.17	50	GAB		66.60	3.97	50
	29.76	2.16	50	NEW		66.36	3.82	50
	30.48	2.60	50	POU		69.13	3.67	50
	28.76	3.50	12	TAS		66.67	3.25	13
	27.14	2.46	18	VED		67.69	3.07	18
XCB	134.18	6.55	445	TOT	ZYB	128.86	8.37	442
	134.16	4.95	50	AND		121.22	4.22	50
	129.83	5.07	76	AUS		130.38	7.27	75
	134.33	3.96	21	BUS		120.08	4.50	20
	138.30	4.63	50	CHI		131.69	6.01	50
	134.67	5.20	52	ESK		135.70	7.25	52
	142.28	3.59	16	FUE		141.17	6.92	16
	132.72	4.82	50	GAB		125.21	6.69	50
	130.16	4.76	50	NEW		129.65	7.71	50
	141.62	6.35	50	POU		130.05	7.48	50
	134.56	5.64	12	TAS		126.01	5.78	11
	126.77	4.73	18	VED		121.39	6.13	18

TABLE A.5.2. CORRELATION COEFFICIENTS (PEARSON) (2-tailed)

FOR 26 TEMPORAL AND 29 NON-TEMPORAL VARIABLES, MEASURED ON 447 MODERN HUNAN CRANIA. * Signif.at p< 0.05, ** Signif.at p <0.01

	ASB	ATANG	AUB	BANG	BANT	BBH
ASB	1.000	.095*	.677**	-.262**	-.063	.408**
ATANG	.095*	1.000	.028	.140**	-.012	.148**
AUB	.677**	.028	1.000	-.274**	.073	.535**
BANG	-.262**	.140**	-.274**	1.000	-.182**	-.246**
BANT	-.063	-.012	.073	-.182**	1.000	.090
BBH	.408**	.148**	.535**	-.246**	.090	1.000
EANG	-.124**	-.124**	-.075	-.088	-.090	.041
ENIN	-.268**	.039	-.012	.003	-.077	-.005
ENOP	.000	.036	.007	-.137**	.077	.199**
FANG	-.230**	.074	-.221**	.119*	-.070	.263**
FMB	.412**	.090	.478**	-.087	.043	.359**
FML	.446**	.241**	.512**	-.119*	.170**	.415**
FPOS	-.038	.006	.020	-.002	-.077	-.031
FRA	.443**	.137**	.417**	-.221**	.209**	.536**
GAP	.458**	.011	.620**	-.148**	.107*	.468**
GFD	.321**	-.149**	.320**	-.304**	.043	.240**
GFA	.405**	-.010	.597**	-.115*	.142**	.461**
GFIDX	.069	.068	.051	.091	.045	.115*
GFV	.479**	-.112*	.590**	-.319**	.083	.423**
GML	.443**	-.051	.629**	-.254**	.071	.402**
GOL	.688**	.208**	.638**	-.212**	.139**	.567**
INOP	.316**	-.007	.407**	-.273**	.219**	.351**
LINC	.393**	.102*	.345**	-.139**	-.078	.353**
MANG	-.219**	-.101*	-.091	.033	.087	-.073
MPD	.485**	.056	.509**	-.138**	-.069	.317**
MPL	.503**	-.007	.507**	-.302**	.018	.401**
MPV	.579**	-.005	.605**	-.295**	-.021	.420**
MPW	.510**	-.084	.534**	-.315**	.017	.380**
MSCANG	-.166**	-.165**	-.188**	-.087	.036	-.068
NBHX	-.230**	-.083	-.387**	.289**	-.082	-.231**
NLH	.518**	.063	.688**	-.311**	.158**	.541**
NLA	.440**	-.016	.528**	-.163**	.127**	.471**
NLB	.170**	-.071	.134**	.065	.041	.195**
OCA	.568**	.076	.543**	-.298**	.040	.440**
OCC	.445**	.135**	.459**	-.219**	.052	.563**
OCCOCA	-.419**	.060	-.345**	.244**	.002	.026
OCNINA	.039	.020	-.143**	-.051	.015	.103*
OIX	-.028	.049	-.113*	.127**	-.186**	-.086
PAA	.407**	.107*	.386**	-.245**	.134**	.609**
PANG	.095*	-.002	.260**	-.172**	-.187**	.029
PPLL	.419**	.094*	.459**	-.150**	.190**	.466**
PTANG	-.065	-.219**	.086	-.176**	.176**	-.002
SCANG	-.024	.114*	.164**	.161**	.056	.014
SCB	.779**	.081	.908**	-.306**	.031	.496**
SCBGOL	.197**	-.142**	.426**	-.143**	-.117*	-.024
SCBXCB	.455**	.137**	.561**	-.011	.048	.323**
SPHO	.501**	-.028	.542**	-.312**	-.007	.376**
TANG	.196**	.291**	.177**	.043	-.452**	.034
TIND	.094*	-.297**	.282**	-.133**	-.157**	-.130**
TPH	.352**	-.074	.395**	-.284**	.081	.353**
TPL	.383**	.062	.556**	-.081	.144**	.409**
TTHK	.287**	.340**	.344**	.002	.218**	.302**
TSQH	.395**	.041	.551**	-.259**	.081	.515**
WCB	.443**	-.038	.626**	-.242**	.068	.404**
XCB	.571**	-.016	.639**	-.363**	-.002	.338**
ZYB	.626**	.084	.883**	-.216**	.141**	.623**

TABLE A.5.2. CORRELATION COEFFICIENTS (CONTD.)

	EANG	ENIN	ENOP	FANG	FMB	FML
ASB	-.124**	-.268**	.000	-.230**	.412**	.446**
ATANG	-.124**	.039	.036	.074	.090	.241**
AUB	-.075	-.012	.007	-.221**	.478**	.512**
BANG	-.088	.003	-.137**	.119*	-.087	-.119*
BANT	-.090	-.077	.077	-.070	.043	.170**
BBH	.041	-.005	.199**	.263**	.359**	.415**
EANG	1.000	.043	.076	-.057	.016	-.061
ENIN	.043	1.000	.573**	.078	-.031	-.215**
ENOP	.076	.573**	1.000	-.035	-.032	-.148**
FANG	-.057	.078	-.035	1.000	-.152**	-.071
FMB	.016	-.031	-.032	-.152**	1.000	.565**
FML	-.061	-.215**	-.148**	-.071	.565**	1.000
FPOS	.049	.706**	.042	.045	-.041	.018
FRA	-.053	-.053	.061	-.182**	.358**	.372**
GAP	.038	.052	.084	-.146**	.325**	.351**
GFD	.091	.049	.021	-.147**	.232**	.197**
GFA	-.003	.025	-.008	-.136**	.324**	.341**
GFIDX	.087	.039	.104*	-.059	.082	.097*
GFV	.059	.054	.035	-.176**	.337**	.322**
GML	-.052	.015	-.020	-.105*	.288**	.292**
GOL	-.059	-.032	.032	-.227**	.481**	.564**
INOP	.012	-.711**	.160**	-.127**	.203**	.128**
LINC	.001	.182**	.067	-.201**	.216**	.311**
MANG	-.031	-.053	.029	.168**	-.124**	-.033
MPDV	-.014	-.002	.058	-.160**	.208**	.197**
MPL	.052	-.057	.088	-.164**	.264**	.200**
MPV	.014	-.035	.054	-.180**	.278**	.250**
MPW	.008	-.041	.016	-.138**	.252**	.221**
MSCANG	.017	-.030	.036	.163**	-.088	-.100*
NBHX	.033	.079	.010	.136**	-.277**	-.366**
NLH	-.018	-.065	.025	-.180**	.440**	.462**
NLA	.009	-.027	.040	-.115*	.313**	.255**
NLB	.029	.029	.036	.005	.048	-.053
OCA	-.009	-.311**	.115*	-.326**	.297**	.331**
OCC	.070	-.181**	.233**	-.179**	.330**	.338**
OCCOCA	.128**	.331**	.143**	.366**	-.062	-.120*
OCNINA	.108*	.348**	.117*	.076	.004	-.096*
OIX	-.036	.620**	-.077	-.016	-.039	.088
PAA	.099*	-.029	.219**	-.112*	.284**	.327**
PANG	.076	.068	-.020	-.162**	.112*	.086
PPL	-.074	-.088	-.005	.034	.356**	.458**
PTANG	.084	-.000	.018	-.086	.038	-.010
SMCANG	-.062	-.024	-.014	-.030	-.014	.109*
SMCB	-.119*	-.001	-.009	-.250**	.454**	.520**
SMCGOL	-.091	.007	-.047	-.061	.024	.010
SMCXCB	-.013	-.337**	-.113*	-.130**	.335**	.372**
SPHO	.039	-.001	-.031	-.331**	.312**	.312**
TANG	-.032	.078	-.046	-.069	.074	.111*
TIND	.054	.025	-.116*	-.155**	.037	-.047
TPH	.103*	-.068	.053	-.024	.091	.237**
TPL	-.079	-.005	.086	-.068	.258**	.273**
TTHK	-.152**	-.041	.004	-.098*	.241**	.391**
TSQH	.114*	-.098*	.086	-.147**	.310**	.397**
WCB	-.082	-.027	.037	-.163**	.361**	.416**
XCB	-.131**	-.123**	.087	-.200**	.276**	.326**
ZYB	-.067	-.328**	.017	-.107*	.479**	.521**

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	FPOS	FRA	GAP	GFD	GFA	GFIDX
ASB	-.038	.443**	.458**	.321**	.405**	.069
ATANG	.006	.137**	.011	-.149**	-.010	.068
AUB	.020	.417**	.620**	.320**	.597**	.051
BANG	-.002	-.221**	-.148**	-.304**	-.115*	.091
BANT	-.077	.209**	.107*	.043	.142**	.045
BBH	-.031	.536**	.468**	.240**	.461**	.115*
EANG	.049	-.053	.038	.091	-.003	.087
ENIN	.706**	-.053	.052	.049	.025	.039
ENOP	.042	.061	.084	.021	-.008	.104*
FANG	.045	-.182**	-.146**	-.147**	-.136**	-.059
FMB	-.041	.358**	.325**	.232**	.324**	.082
FML	.018	.372**	.351**	.197**	.341**	.097*
FPOS	1.000	-.059	.053	.031	.044	.007
FRA	-.059	1.000	.363**	.272**	.339**	.101*
GAP	.053	.363**	1.000	.332**	.607**	.544**
GFD	.031	.272**	.332**	1.000	.257**	-.020
GFA	.044	.339**	.607**	.257**	1.000	-.086
GFIDX	.007	.101*	.544**	-.020	-.086	1.000
GFV	.054	.382**	.699**	.865**	.585**	.042
GML	.050	.306**	.548**	.387**	.751**	-.400**
GOL	-.030	.707**	.548**	.329**	.502**	.152**
INOP	.032	.306**	.346**	.258**	.379**	.022
LINC	-.070	.240**	.218**	.123**	.202**	.097*
MANG	.007	-.276**	-.149**	-.061	-.050	-.100*
MPD	-.042	.209**	.410**	.248**	.362**	.044
MPL	-.103*	.350**	.396**	.386**	.350**	.011
MPV	-.075	.347**	.445**	.376**	.392**	.025
MPW	-.105*	.330**	.348**	.363**	.310**	.006
MSCANGL	.003	-.135**	-.166**	.090	-.061	-.198**
NBHX	.107*	-.150**	-.221**	-.133**	-.209**	-.047
NLH	-.099*	.366**	.533**	.326**	.517**	.074
NLA	-.050	.314**	.466**	.297**	.460**	.036
NLB	.029	.129**	.197**	.133**	.200**	-.008
OCA	-.005	.417**	.398**	.251**	.405**	.099*
OCC	.000	.328**	.345**	.201**	.345**	.112*
OCCOCA	.009	-.309**	-.238**	-.170**	-.251**	-.022
OCNINA	-.047	.131**	-.136**	.060	-.191**	-.002
OIX	-.038	-.106*	-.137**	-.133**	-.185**	.032
PAA	-.060	.419**	.324**	.258**	.252**	.124**
PANG	.065	.059	.053	.076	.025	-.002
PPL	-.099*	.353**	.305**	.220**	.337**	.042
PTANG	.014	.082	-.010	.158**	-.044	.012
SCANG	.005	-.137**	.060	-.206**	.032	.152**
SCB	-.004	.445**	.558**	.348**	.528**	.048
SCBGOL	.011	-.250**	.077	.064	.096*	-.120*
SCBXCB	.019	.186**	.460**	.176**	.458**	.144**
SPHO	-.047	.302**	.416**	.367**	.448**	.017
TANG	.056	-.045	.073	-.125**	.090	-.020
TIND	.063	-.077	.020	-.058	.004	-.034
TPH	-.100*	.159**	.248**	.313**	.224**	.015
TPL	.007	.304**	.458**	.249**	.456**	.008
TTHK	-.034	.370**	.380**	.094*	.269**	.238**
TSQH	-.148**	.333**	.417**	.245**	.351**	.132**
WCB	-.050	.384**	.391**	.299**	.361**	.057
XCB	-.020	.390**	.300**	.279**	.264**	-.060
ZYB	-.016	.439**	.654**	.299**	.647**	.051

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	GFV	GML	GOL	INOP	LINC	MANG
ASB	.479**	.443**	.688**	.316**	.393**	-.219**
ATANG	-.112*	-.051	.208**	-.007	.102*	-.101*
AUB	.590**	.629**	.638**	.407**	.345**	-.091
BANG	-.319**	-.254**	-.212**	-.273**	-.139**	.033
BANT	.083	.071	.139**	.219**	-.078	.087
BBH	.423**	.402**	.567**	.351**	.353**	-.073
EANG	.059	-.052	-.059	.012	.001	-.031
ENIN	.054	.015	-.032	-.711**	.182**	-.053
ENOP	.035	-.020	.032	.160**	.067	.029
FANG	-.176**	-.105*	-.227**	-.127**	-.201**	.168**
FMB	.337**	.288**	.481**	.203**	.216**	-.124**
FML	.322**	.292**	.564**	.128**	.311**	-.033
FPOS	.054	.050	-.030	.032	-.070	.007
FRA	.382**	.306**	.707**	.306**	.240**	-.276**
GAP	.699**	.548**	.548**	.346**	.218**	-.149**
GFD	.865**	.387**	.329**	.258**	.123**	-.061
GFA	.585**	.751**	.502**	.379**	.202**	-.050
GFIDX	.042	-.400**	.152**	.022	.097*	-.100*
GFV	1.000	.725**	.520**	.381**	.191**	-.104*
GML	.725**	1.000	.455**	.357**	.146**	-.070
GOL	.520**	.455**	1.000	.471**	.416**	-.305**
INOP	.381**	.357**	.471**	1.000	-.167**	-.087
LINC	.191**	.146**	.416**	-.167**	1.000	-.136**
MANG	-.104*	-.070	-.305**	-.087	-.136**	1.000
MPD	.408**	.409**	.410**	.229**	.186**	-.145**
MPL	.502**	.429**	.487**	.262**	.296**	-.341**
MPV	.519**	.468**	.517**	.306**	.304**	-.247**
MPW	.453**	.380**	.441**	.294**	.300**	-.190**
MSCANG	.013	.015	-.204**	-.058	-.156**	.723**
NBHX	-.212**	-.193**	-.291**	-.216**	-.206**	-.082
NHAV	.532**	.514**	.601**	.389**	.289**	-.050
NLA	.483**	.480**	.491**	.298**	.188**	-.116*
NLB	.219**	.229**	.171**	.078	.004	-.137**
OCA	.387**	.341**	.715**	.471**	.745**	-.234**
OCC	.319**	.270**	.580**	.413**	.745**	-.146**
OCCOCA	-.255**	-.243**	-.498**	-.278**	-.294**	.235**
OCNINA	-.051	-.142**	.029	-.321**	.294**	-.023
OIX	-.183**	-.182**	-.131**	-.822**	.633**	-.015
PAA	.338**	.236**	.616**	.318**	.149**	-.160**
PANG	.083	.059	.044	.047	.121*	-.039
PPL	.322**	.297**	.467**	.277**	.232**	-.030
PTANG	.092	-.022	-.028	.071	.028	.050
SCANG	-.139**	-.089	-.073	-.018	.058	.189**
SCB	.569**	.570**	.671**	.388**	.394**	-.134**
SCBGOL	.127**	.205**	-.302**	-.051	.020	.183**
SCBXCB	.370**	.364**	.513**	.307**	.099*	-.201**
SPHO	.499**	.441**	.498**	.324**	.303**	-.111*
TANG	-.029	.099*	.088	-.044	.103*	-.115*
TIND	-.012	.057	-.073	-.051	.096*	.020
TPH	.354**	.258**	.284**	.215**	.271**	-.002
TPL	.449**	.492**	.425**	.273**	.177**	-.092
TTHK	.233**	.186**	.507**	.257**	.157**	-.226**
TSQH	.386**	.320**	.492**	.295**	.357**	-.035
WCB	.429**	.379**	.469**	.256**	.293**	-.051
XCB	.389**	.394**	.394**	.219**	.397**	.003
ZYB	.600**	.668**	.679**	.405**	.315**	-.106*

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	MPD	MPL	MPV	MPW	MSCANG	NBHX
ASB	.485**	.503**	.579**	.510**	-.166**	-.230**
ATANG	.056	-.007	-.005	-.084	-.165**	-.083
AUB	.509**	.507**	.605**	.534**	-.188**	-.387**
BANG	-.138**	-.302**	-.295**	-.315**	-.087	.289**
BANT	-.069	.018	-.021	.017	.036	-.082
BBH	.317**	.401**	.420**	.380**	-.068	-.231**
EANG	-.014	.052	.014	.008	.017	.033
ENIN	-.002	-.057	-.035	-.041	-.030	.079
ENOP	.058	.088	.054	.016	.036	.010
FANG	-.160**	-.164**	-.180**	-.138**	.163**	.136**
FMB	.208**	.264**	.278**	.252**	-.088	-.277**
FML	.197**	.200**	.250**	.221**	-.100*	-.366**
FPOS	-.042	-.103*	-.075	-.105*	.003	.107*
FRA	.209**	.350**	.347**	.330**	-.135**	-.150**
GAP	.410**	.396**	.445**	.348**	-.166**	-.221**
GFD	.248**	.386**	.376**	.363**	.090	-.133**
GFA	.362**	.350**	.392**	.310**	-.061	-.209**
GFIDX	.044	.011	.025	.006	-.198**	-.047
GFV	.408**	.502**	.519**	.453**	.013	-.212**
GML	.409**	.429**	.468**	.380**	.015	-.193**
GOL	.410**	.487**	.517**	.441**	-.204**	-.291**
INOP	.229**	.262**	.306**	.294**	-.058	-.216**
LINC	.186**	.296**	.304**	.300**	-.156**	-.206**
MANG	-.145**	-.341**	-.247**	-.190**	.723**	-.082
MPD	1.000	.622**	.852**	.580**	-.099*	-.050
MPL	.622**	1.000	.854**	.644**	-.137**	-.112*
MPV	.852**	.854**	1.000	.868**	-.098*	-.131**
MPW	.580**	.644**	.868**	1.000	-.048	-.137**
MSCANG	-.099*	-.137**	-.098*	-.048	1.000	.031
NBHX	-.050	-.112*	-.131**	-.137**	.031	1.000
NLH	.351**	.469**	.494**	.445**	-.053	-.587**
NLA	.395**	.486**	.504**	.442**	-.020	.061
NLB	.253**	.283**	.280**	.227**	.006	.686**
OCA	.315**	.416**	.453**	.431**	-.211**	-.289**
OCC	.225**	.342**	.347**	.329**	-.160**	-.256**
OCCOCA	-.259**	-.276**	-.340**	-.325**	.172**	.163**
OCNINA	-.060	.121*	.036	.046	.111*	.143**
OIX	-.079	-.045	-.075	-.065	-.040	.048
PAA	.282**	.332**	.328**	.250**	-.072	-.156**
PANG	.005	-.065	-.029	-.040	-.152**	-.239**
PPL	.273**	.348**	.375**	.356**	.007	-.228**
PTANG	-.229**	-.056	-.109*	-.004	.038	-.164**
SCANG	-.024	-.218**	-.157**	-.166**	-.534**	-.146**
SCB	.513**	.520**	.621**	.560**	-.205**	-.354**
SCBGOL	.185**	.105*	.198**	.205**	-.027	-.116*
SCBXCB	.396**	.322**	.354**	.216**	-.332**	-.163**
SPHO	.429**	.445**	.563**	.572**	-.069	-.192**
TANG	.314**	.006	.114*	-.040	-.225**	-.044
TIND	.076	.053	.113*	.141**	-.071	-.049
TPH	.191**	.393**	.353**	.361**	.009	-.230**
TPL	.410**	.433**	.473**	.397**	-.104*	-.116*
TTHK	.141**	.185**	.137**	.046	-.313**	-.325**
TSQH	.322**	.342**	.418**	.386**	-.124**	-.385**
WCB	.397**	.454**	.487**	.408**	-.078	-.265**
XCB	.300**	.367**	.465**	.502**	.028	-.294**
ZYB	.532**	.557**	.618**	.512**	-.142**	-.330**

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	NLH	NLA	NLB	OCA	OCC	OCCOCA
ASB	.518**	.440**	.170**	.568**	.445**	-.419**
ATANG	.063	-.016	-.071	.076	.135**	.060
AUB	.688**	.528**	.134**	.543**	.459**	-.345**
BANG	-.311**	-.163**	.065	-.298**	-.219**	.244**
BANT	.158**	.127**	.041	.040	.052	.002
BBH	.541**	.471**	.195**	.440**	.563**	.026
EANG	-.018	.009	.029	-.009	.070	.128**
ENIN	-.065	-.027	.029	-.311**	-.181**	.331**
ENOP	.025	.040	.036	.115*	.233**	.143**
FANG	-.180**	-.115*	.005	-.326**	-.179**	.366**
FMB	.440**	.313**	.048	.297**	.330**	-.062
FML	.462**	.255**	-.053	.331**	.338**	-.120*
FPOS	-.099*	-.050	.029	-.005	.000	.009
FRA	.366**	.314**	.129**	.417**	.328**	-.309**
GAP	.533**	.466**	.197**	.398**	.345**	-.238**
GFD	.326**	.297**	.133**	.251**	.201**	-.170**
GFA	.517**	.460**	.200**	.405**	.345**	-.251**
GFIDX	.074	.036	-.008	.099*	.112*	-.022
GFV	.532**	.483**	.219**	.387**	.319**	-.255**
GML	.514**	.480**	.229**	.341**	.270**	-.243**
GOL	.601**	.491**	.171**	.715**	.580**	-.498**
INOP	.389**	.298**	.078	.471**	.413**	-.278**
LINC	.289**	.188**	.004	.745**	.745**	-.294**
MANG	-.050	-.116*	-.137**	-.234**	-.146**	.235**
MPD	.351**	.395**	.253**	.315**	.225**	-.259**
MPL	.469**	.486**	.283**	.416**	.342**	-.276**
MPV	.494**	.504**	.280**	.453**	.347**	-.340**
MPW	.445**	.442**	.227**	.431**	.329**	-.325**
MSCANG	-.053	-.020	.006	-.211**	-.160**	.172**
NBHX	-.587**	.061	.686**	-.289**	-.256**	.163**
NLH	1.000	.767**	.180**	.460**	.442**	-.206**
NLA	.767**	1.000	.766**	.325**	.330**	-.117*
NLB	.180**	.766**	1.000	.050	.078	.025
OCA	.460**	.325**	.050	1.000	.866**	-.609**
OCC	.442**	.330**	.078	.866**	1.000	-.132**
OCCOCA	-.206**	-.117*	.025	-.609**	-.132**	1.000
OCNINA	-.042	.071	.146**	.012	.181**	.270**
OIX	-.141**	-.134**	-.068	.037	.067	.033
PAA	.376**	.337**	.150**	.305**	.338**	-.068
PANG	.065	-.108*	-.231**	.146**	.093	-.142**
PPL	.492**	.413**	.150**	.338**	.347**	-.115*
PTANG	.031	-.086	-.164**	.062	.023	-.087
SCANG	.021	-.106*	-.172**	.020	.056	.042
SCB	.637**	.495**	.131**	.582**	.496**	-.363**
SCBGOL	.123**	.067	-.027	-.087	-.041	.113*
SCBXCB	.450**	.410**	.196**	.304**	.242**	-.225**
SPHO	.495**	.457**	.207**	.472**	.371**	-.349**
TANG	.030	-.004	-.035	.083	.075	-.047
TIND	.043	.021	-.017	.055	-.016	-.140**
TPH	.396**	.305**	.075	.335**	.337**	-.130**
TPL	.404**	.398**	.218**	.312**	.303**	-.133**
TTHK	.372**	.174**	-.080	.321**	.280**	-.196**
TSQH	.530**	.342**	.003	.454**	.473**	-.146**
WCB	.540**	.443**	.149**	.388**	.360**	-.196**
XCB	.404**	.263**	-.000	.456**	.405**	-.255**
ZYB	.713**	.601**	.222**	.504**	.444**	-.289**

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	OCNINA	OIX	PAA	PANG	PPL	PTANG
ASB	.039	-.028	.407**	.095*	.419**	-.065
ATANG	.020	.049	.107*	-.002	.094*	-.219**
AUB	-.143**	-.113*	.386**	.260**	.459**	.086
BANG	-.051	.127**	-.245**	-.172**	-.150**	-.176**
BANT	.015	-.186**	.134**	-.187**	.190**	.176**
BBH	.103*	-.086	.609**	.029	.466**	-.002
EANG	.108*	-.036	.099*	.076	-.074	.084
ENIN	.348**	.620**	-.029	.068	-.088	-.000
ENOP	.117*	-.077	.219**	-.020	-.005	.018
FANG	.076	-.016	-.112*	-.162**	.034	-.086
FMB	.004	-.039	.284**	.112*	.356**	.038
FML	-.096*	.088	.327**	.086	.458**	-.010
FPOS	-.047	-.038	-.060	.065	-.099*	.014
FRA	.131**	-.106*	.419**	.059	.353**	.082
GAP	-.136**	-.137**	.324**	.053	.305**	-.010
GFD	.060	-.133**	.258**	.076	.220**	.158**
GFA	-.191**	-.185**	.252**	.025	.337**	-.044
GFIDX	-.002	.032	.124**	-.002	.042	.012
GFV	-.051	-.183**	.338**	.083	.322**	.092
GML	-.142**	-.182**	.236**	.059	.297**	-.022
GOL	.029	-.131**	.616**	.044	.467**	-.028
INOP	-.321**	-.822**	.318**	.047	.277**	.071
LINC	.294**	.633**	.149**	.121*	.232**	.028
MANG	-.023	-.015	-.160**	-.039	-.030	.050
MPD	-.060	-.079	.282**	.005	.273**	-.229**
MPL	.121*	-.045	.332**	-.065	.348**	-.056
MPV	.036	-.075	.328**	-.029	.375**	-.109*
MPW	.046	-.065	.250**	-.040	.356**	-.004
MSCANG	.111*	-.040	-.072	-.152**	.007	.038
NBHX	.143**	.048	-.156**	-.239**	-.228**	-.164**
NLH	-.042	-.141**	.376**	.065	.492**	.031
NLA	.071	-.134**	.337**	-.108*	.413**	-.086
NLB	.146**	-.068	.150**	-.231**	.150**	-.164**
OCA	.012	.037	.305**	.146**	.338**	.062
OCC	.181**	.067	.338**	.093	.347**	.023
OCCOCA	.270**	.033	-.068	-.142**	-.115*	-.087
OCNINA	1.000	.371**	.210**	-.126**	.017	.011
OIX	.371**	1.000	-.156**	.048	-.070	-.019
PAA	.210**	-.156**	1.000	.058	.287**	.010
PANG	-.126**	.048	.058	1.000	-.186**	.686**
PPL	.017	-.070	.287**	-.186**	1.000	-.175**
PTANG	.011	-.019	.010	.686**	-.175**	1.000
SCANG	-.188**	.034	-.094*	.167**	-.038	-.000
SCB	-.059	-.081	.419**	.216**	.493**	.032
SCBGOL	-.115*	.049	-.177**	.223**	.092	.071
SCBXCB	-.253**	-.176**	.322**	.054	.314**	-.101*
SPHO	-.046	-.086	.342**	.086	.340**	.020
TANG	-.154**	.083	.052	.204**	.027	-.572**
TIND	-.088	.103*	-.093*	.180**	-.088	.061
TPH	.081	-.015	.218**	.041	.312**	.095*
TPL	-.005	-.097*	.241**	-.079	.330**	-.156**
TTHK	-.130**	-.094*	.245**	.065	.244**	-.025
TSQH	-.001	-.046	.431**	.115*	.402**	.073
WCB	.024	-.046	.270**	.075	.370**	.022
XCB	.137**	.045	.248**	.219**	.340**	.122*
ZYB	-.129**	-.135**	.416**	.086	.496**	-.035

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	SCANG	SCB	SCBGOL	SCBXCB	SPHO	TANG
ASB	-.024	.779**	.197**	.455**	.501**	.196**
ATANG	.114*	.081	-.142**	.137**	-.028	.291**
AUB	.164**	.908**	.426**	.561**	.542**	.177**
BANG	.161**	-.306**	-.143**	-.011	-.312**	.043
BANT	.056	.031	-.117*	.048	-.007	-.452**
BBH	.014	.496**	-.024	.323**	.376**	.034
EANG	-.062	-.119*	-.091	-.013	.039	-.032
ENIN	-.024	-.001	.007	-.337**	-.001	.078
ENOP	-.014	-.009	-.047	-.113*	-.031	-.046
FANG	-.030	-.250**	-.061	-.130**	-.331**	-.069
FMB	-.014	.454**	.024	.335**	.312**	.074
FML	.109*	.520**	.010	.372**	.312**	.111*
FPOS	.005	-.004	.011	.019	-.047	.056
FRA	-.137**	.445**	-.250**	.186**	.302**	-.045
GAP	.060	.558**	.077	.460**	.416**	.073
GFD	-.206**	.348**	.064	.176**	.367**	-.125**
GFA	.032	.528**	.096*	.458**	.448**	.090
GFIDX	.152**	.048	-.120*	.144**	.017	-.020
GFV	-.139**	.569**	.127**	.370**	.499**	-.029
GML	-.089	.570**	.205**	.364**	.441**	.099*
GOL	-.073	.671**	-.302**	.513**	.498**	.088
INOP	-.018	.388**	-.051	.307**	.324**	-.044
LINC	.058	.394**	.020	.099*	.303**	.103*
MANG	.189**	-.134**	.183**	-.201**	-.111*	-.115*
MPD	-.024	.513**	.185**	.396**	.429**	.314**
MPL	-.218**	.520**	.105*	.322**	.445**	.006
MPV	-.157**	.621**	.198**	.354**	.563**	.114*
MPWL	-.166**	.560**	.205**	.216**	.572**	-.040
MSCANG	-.534**	-.205**	-.027	-.332**	-.069	-.225**
NBHX	-.146**	-.354**	-.116*	-.163**	-.192**	-.044
NLH	.021	.637**	.123**	.450**	.495**	.030
NLA	-.106*	.495**	.067	.410**	.457**	-.004
NLB	-.172**	.131**	-.027	.196**	.207**	-.035
OCA	.020	.582**	-.087	.304**	.472**	.083
OCC	.056	.496**	-.041	.242**	.371**	.075
OCCOCA	.042	-.363**	.113*	-.225**	-.349**	-.047
OCNINA	-.188**	-.059	-.115*	-.253**	-.046	-.154**
OIX	.034	-.081	.049	-.176**	-.086	.083
PAA	-.094*	.419**	-.177**	.322**	.342**	.052
PANG	.167**	.216**	.223**	.054	.086	.204**
PPL	-.038	.493**	.092	.314**	.340**	.027
PTANG	-.000	.032	.071	-.101*	.020	-.572**
SCANG	1.000	.134**	.260**	.239**	-.033	.188**
SCB	.134**	1.000	.503**	.575**	.549**	.201**
SCBGOL	.260**	.503**	1.000	.144**	.122**	.155**
SCBXCB	.239**	.575**	.144**	1.000	.342**	.200**
SPHO	-.033	.549**	.122**	.342**	1.000	.071
TANG	.188**	.201**	.155**	.200**	.071	1.000
TIND	.123**	.248**	.407**	.044	.130**	.121*
TPH	-.026	.408**	.195**	.197**	.317**	-.082
TPL	.041	.483**	.126**	.286**	.356**	.122**
TTHK	.179**	.325**	-.170**	.410**	.145**	.106*
TSQH	.133**	.553**	.144**	.393**	.388**	.027
WCB	.058	.583**	.208**	.285**	.390**	.052
XCB	-.036	.739**	.489**	-.125**	.386**	.080
ZYB	.082	.786**	.222**	.576**	.516**	.144**

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	TIND	TPH	TPL	TTHK	TSQH	WCB
ASB	.094*	.352**	.383**	.287**	.395**	.443**
ATANG	-.297**	-.074	.062	.340**	.041	-.038
AUB	.282**	.395**	.556**	.344**	.551**	.626**
BANG	-.133**	-.284**	-.081	.002	-.259**	-.242**
BANT	-.157**	.081	.144**	.218**	.081	.068
BBH	-.130**	.353**	.409**	.302**	.515**	.404**
EANG	.054	.103*	-.079	-.152**	.114*	-.082
ENIN	.025	-.068	-.005	-.041	-.098*	-.027
ENOP	-.116*	.053	.086	.004	.086	.037
FANG	-.155**	-.024	-.068	-.098*	-.147**	-.163**
FMB	.037	.091	.258**	.241**	.310**	.361**
FML	-.047	.237**	.273**	.391**	.397**	.416**
FPOS	.063	-.100*	.007	-.034	-.148**	-.050
FRA	-.077	.159**	.304**	.370**	.333**	.384**
GAP	.020	.248**	.458**	.380**	.417**	.391**
GFD	-.058	.313**	.249**	.094*	.245**	.299**
GFA	.004	.224**	.456**	.269**	.351**	.361**
GFIDX	-.034	.015	.008	.238**	.132**	.057
GFV	-.012	.354**	.449**	.233**	.386**	.429**
GML	.057	.258**	.492**	.186**	.320**	.379**
GOL	-.073	.284**	.425**	.507**	.492**	.469**
INOP	-.051	.215**	.273**	.257**	.295**	.256**
LINC	.096*	.271**	.177**	.157**	.357**	.293**
MANG	.020	-.002	-.092	-.226**	-.035	-.051
MPD	.076	.191**	.410**	.141**	.322**	.397**
MPL	.053	.393**	.433**	.185**	.342**	.454**
MPV	.113*	.353**	.473**	.137**	.418**	.487**
MPW	.141**	.361**	.397**	.046	.386**	.408**
MSCANG	-.071	.009	-.104*	-.313**	-.124**	-.078
NBHX	-.049	-.230**	-.116*	-.325**	-.385**	-.265**
NLH	.043	.396**	.404**	.372**	.530**	.540**
NLA	.021	.305**	.398**	.174**	.342**	.443**
NLB	-.017	.075	.218**	-.080	.003	.149**
OCA	.055	.335**	.312**	.321**	.454**	.388**
OCC	-.016	.337**	.303**	.280**	.473**	.360**
OCCOCA	-.140**	-.130**	-.133**	-.196**	-.146**	-.196**
OCNINA	-.088	.081	-.005	-.130**	-.001	.024
OIX	.103*	-.015	-.097*	-.094*	-.046	-.046
PAA	-.093*	.218**	.241**	.245**	.431**	.270**
PANG	.180**	.041	-.079	.065	.115*	.075
PPL	-.088	.312**	.330**	.244**	.402**	.370**
PTANG	.061	.095*	-.156**	-.025	.073	.022
SCANG	.123**	-.026	.041	.179**	.133**	.058
SCB	.248**	.408**	.483**	.325**	.553**	.583**
SCBGOL	.407**	.195**	.126**	-.170**	.144**	.208**
SCBXCB	.044	.197**	.286**	.410**	.393**	.285**
SPHO	.130**	.317**	.356**	.145**	.388**	.390**
TANG	.121*	-.082	.122**	.106*	.027	.052
TIND	1.000	-.006	-.166**	-.273**	.001	.112*
TPH	-.006	1.000	.321**	.202**	.301**	.309**
TPL	-.166**	.321**	1.000	.319**	.277**	.412**
TTHK	-.273**	.202**	.319**	1.000	.328**	.218**
TSQH	.001	.301**	.277**	.328**	1.000	.373**
WCB	.112*	.309**	.412**	.218**	.373**	1.000
XCB	.266**	.334**	.349**	.055	.352**	.472**
ZYB	.061	.347**	.598**	.353**	.530**	.626**

TABLE A.5.2 CORRELATION COEFFICIENTS (CONTD.)

	XCB	ZYB	LBH
ASB	.571**	.626**	.705**
ATANG	-.016	.084	.145**
AUB	.639**	.883**	.874**
BANG	-.363**	-.216**	-.290**
BANT	-.002	.141**	.116*
BBH	.338**	.623**	.807**
EANG	-.131**	-.067	-.040
ENIN	-.123**	-.328**	-.346**
ENOP	.087	.017	.086
FANG	-.200**	-.107*	-.090
FMB	.276**	.479**	.521**
FML	.326**	.521**	.588**
FPOS	-.020	-.016	-.017
FRA	.390**	.439**	.642**
GAP	.300**	.654**	.650**
GFD	.279**	.299**	.352**
GFA	.264**	.647**	.618**
GFIDX	-.060	.051	.123**
GFV	.389**	.600**	.609**
GML	.394**	.668**	.594**
GOL	.394**	.679**	.862**
INOP	.219**	.405**	.483**
LINC	.397**	.315**	.438**
MANG	.003	-.106*	-.182**
MPD	.300**	.532**	.494**
MPL	.367**	.557**	.554**
MPV	.465**	.618**	.615**
MPW	.502**	.512**	.540**
MSCANG	.028	-.142**	-.186**
NBHX	-.294**	-.330**	-.363**
NLH	.404**	.713**	.723**
NLA	.263**	.601**	.585**
NLB	-.000	.222**	.193**
OCA	.456**	.504**	.668**
OCC	.405**	.444**	.623**
OCCOCA	-.255**	-.289**	-.332**
OCNINA	.137**	-.129**	-.016
OIX	.045	-.135**	-.130**
PAA	.248**	.416**	.621**
PANG	.219**	.086	.144**
PPL	.340**	.496**	.546**
PTANG	.122*	-.035	.028
SCANG	-.036	.082	.051
SCB	.739**	.786**	.832**
SCBGOL	.489**	.222**	.065
SCBXCB	-.125**	.576**	.559**
SPHO	.386**	.516**	.561**
TANG	.080	.144**	.126**
TIND	.266**	.061	.050
TPH	.334**	.347**	.409**
TPL	.349**	.598**	.553**
TTHK	.055	.353**	.452**
TSQH	.352**	.530**	.619**
WCB	.472**	.626**	.599**
XCB	1.000	.481**	.551**
ZYB	.481**	1.000	.869**

* - Signif. LE .05 ** - Signif. LE .01

TABLE A.5.3 CRANIAL SIZE GROUP MEANS

Cranial Size (LBH) = cub.rt.[GOL x AUB x BBH]/100

	AND	BUS	VED	GAB	TAS	NEW	AUS	CHI	POU	ESK	FUE
LBH	1.326	1.346	1.371	1.382	1.399	1.405	1.412	1.434	1.437	1.470	1.494
SD	.04	.040	.052	.051	.039	.050	.054	.047	.061	.049	.054
No.	50	21	18	50	11	50	76	50	50	52	50

TABLE A.5.4 CORRELATION OF 26 TEMPORAL VARIABLES WITH CRANIAL SIZE.

(i) 11 GROUPS COMBINED and
(ii) VARIABLE GROUP MEANS WITH CRANIAL SIZE GROUP MEANS
(2-tailed Significance)

(i) CORRELATION OF TEMPORAL VARIABLES WITH CRANIAL SIZE FOR TOTAL COMBINED SAMPLE.

VARIABLE	POSITIVE CORR.COEF.	SIG. p<.001	NO.of CASES
GAP	.650	.000	444
GFA	.618	.000	444
TSQH	.619	.000	443
MPV	.615	.000	441
GFV	.609	.000	444
GML	.594	.000	444
MPL	.554	.000	442
TPL	.553	.000	444
PPL	.546	.000	444
MPW	.540	.000	444
MPD	.494	.000	443
TTHK	.452	.000	444
TPH	.409	.000	444
GFD	.352	.000	444
FPOS	.235	.000	442

VARIABLE	NEGATIVE CORR.COEF.	SIG. p<.001	NO.of CASES
MSCANG	-.186	.000	444
MANG	-.182	.000	444

VARIABLE	NEGLIGIBLE CORRELATION	SIG. p>.001	NO.of CASES
ATANGS	.145	.002	443
PANGS	.144	.002	443
TANGS	.126	.008	444
GFIDX	.123	.010	444
BANT	.116	.015	442
TIND	.050	.293	444
SCANG	.051	.283	444
EANG	-.040	.400	441
PTANG	.028	.564	442

(ii) CORRELATION OF TEMPORAL VARIABLE GROUP MEANS WITH CRANIAL SIZE GROUP MEANS.

VARIABLE	POSITIVE CORR.COEF.	SIG. p<.001	NO.of CASES
GAP	.897	.000	11
GFA	.940	.000	11
TSQH	.773	.005	11
MPV	.754	.007	11
GFV	.849	.001	11
GML	.865	.001	11
MPL	.660	.027	11
TPL	.884	.000	11
PPL	.537	.089	11
MPW	.703	.016	11
MPD	.752	.008	11
TTHK	.689	.019	11
TPH	.575	.064	11
GFD	.453	.162	11
FPOS	.182	.593	11

VARIABLE	NEGATIVE CORR.COEF.	SIG. p<.001	NO.of CASES
MSCANG	-.568	.068	11
MANG	-.193	.569	11

VARIABLE	NEGLIGIBLE CORRELATION	SIG. p>.001	NO.of CASES
ATANGS	.044	.898	11
PANGS	.220	.516	11
TANGS	.356	.282	11
GFIDX	.467	.147	11
BANT	.582	.060	11
TIND	.374	.258	11
SCANG	.467	.147	11
EANG	.219	.517	11
PTANG	-.036	.917	11

TABLE A.5.5.
F RATIOS FROM ONEWAY ANALYSIS OF VARIANCE

Scheffe's Test in One-Way Analysis of Variance was applied to measurements taken from 11 modern human population samples for 56 cranial variables (26 temporal and 30 non-temporal). As the F ratios indicate, differences between the groups are significant at p<.0001 for all but 3 variables.

TEMPORAL VARIABLE STATISTICS				NON-TEMP. VARIABLE STATISTICS			
VARIABLE	NO.CASES	F RATIO	p<.0001	VARIABLE	NO.CASES	F RATIO	p<.0001
ATANGS	443	13.9	.0000	ASB	444	28.2	.0000
FPOS	442	4.54	.0000	AUB	444	43.8	.0000
QGAP *	444	20.8	.0000	BANG	442	14.3	.0000
QGFA *	444	19.3	.0000	BBH	444	12.5	.0000
GFD	444	9.96	.0000	ENIN	444	9.08	.0000
QGFIDX *	444	4.89	.0000	FANG	442	9.37	.0000
QGML *	444	14.3	.0000	FRA	444	13.4	.0000
QGFV *	444	14.9	.0000	LBH	443	34.8	.0000
MANG	444	8.74	.0000	GOL	444	39.1	.0000
MPD	443	8.55	.0000	INOP	444	11.1	.0000
MPL	442	14.6	.0000	LFMB **	444	7.04	.0000
MPV	441	16.6	.0000	LFML **	443	18.8	.0000
LMPW **	444	20.1	.0000	LINC	444	8.68	.0000
MSCANG	444	11.6	.0000	LOIX **	444	4.37	.0000
PANGS	443	11.9	.0000	LSCBGOL**	444	22.1	.0000
PPL	444	10.7	.0000	NBHX	443	57.7	.0000
PTANG	442	6.77	.0000	NLA	443	14.6	.0000
QSCANG *	444	25.0	.0000	NLH	443	29.9	.0000
TANGS	444	6.54	.0000	NLB	443	26.0	.0000
TIND	444	13.0	.0000	OCA	444	20.6	.0000
QTPH *	444	17.9	.0000	OCCOCA	444	29.5	.0000
QTPL *	444	11.5	.0000	OCNINA	443	11.5	.0000
TSQH	443	24.4	.0000	PAA	444	8.64	.0000
QTTHK *	444	42.1	.0000	SCB	444	39.0	.0000
				QSCXCB *	444	46.5	.0000
				SPHO	443	22.8	.0000
				WCB	444	11.7	.0000
				XCB	444	31.6	.0000
				ZYB	442	24.7	.0000
VARIABLE	NO.CASES	F RATIO	p>.001	VARIABLE	NO.CASES	F RATIO	p>.001
BANT	442	2.64	.004				
EANG	441	2.36	.01	ENOP	444	.976	.464

* Variables transformed by square root to minimise skewness and kurtosis.
** Variables transformed by $\log_{10}$ to minimise skewness and kurtosis.

ONEWAY ANALYSIS OF VARIANCE of 26 TEMPORAL VARIABLES in 11 GROUPS. RESULTS OF SCHEFFES'S TEST.

TABLE A.5.6.1 NO. OF LINEAR TEMPORAL VARIABLES WITH SIGNIFICANT DIFFERENCE IN MEANS BETWEEN PAIRS OF GROUPS.
(17 Linear Variables are involved).

Each number in the tables refers to the number of variables which Scheffe's test shows are significantly greater for the vertically named group than for the corresponding horizontally listed group. The groups are named with increasing cranial size from left to right and from top to bottom

	AND	BUS	VED	GAB	TAS	NEW	AUS	CHI	POU	ESK	FUE
AND							1				
BUS	1					1					
VED	1										
GAB	4										
TAS	1	3	1								
NEW	9	5	1	2	2						
AUS	10	6	2	6	1	1		1			
CHI	13	10	4	7	6	3	4			4	
POU	12	9	5	7	6	2	5			4	
ESK	8	6	4	4	4	3	2	1	1		1
FUE	12	8	7	7	6	2	3	2	3	4	

TABLE A.5.6.2 NO. OF NON-LINEAR TEMPORAL VARIABLES WITH SIGNIFICANT DIFFERENCE IN MEANS BETWEEN PAIRS OF GROUPS.
(1 Ratio and 8 Angular Variables are involved).

	AND	BUS	VED	GAB	TAS	NEW	AUS	CHI	POU	ESK	FUE
AND		1		1		2	4		2	2	
BUS								1			
VED										1	
GAB	1						1	1	1	1	
TAS				1			2		1		
NEW							1		1		
AUS								1		1	
CHI		1		1			4		1	1	
POU				1			2			1	
ESK	3	2	3	3		3	3	4	4		1
FUE							1		1		

TABLE A.5.6.3 TOTAL NUMBER OF SIGNIFICANT DIFFERENCES IN TEMPORAL VARIABLE GROUP MEANS FOR EACH OF 11 GROUPS.

GP	17 LINEAR TEMP. VARS.			9 NON- LINEAR TEMP. VARS.			26 TEMP VARS
	No.sig. smaller means	No.sig. larger means	No.sig. diff-erent means	No.sig. smaller means	No.sig. larger means	No.sig. diff-erent means	No.sig. diff-erent means
AND	**72**	1	**73**	4	12	16	**89**
BUS	46	2	48	4	1	5	53
VED	24	1	**25**	3	1	4	**29**
GAB	33	4	**37**	7	5	12	**49**
TAS	25	5	30	0	4	4	34
NEW	12	19	41	5	2	7	48
AUS	15	27	42	**18**	2	**20**	62
CHI	4	51	**55**	7	8	15	**73**
POU	4	48	52	11	4	15	67
ESK	12	34	46	7	**26**	**27**	**73**
FUE	1	**54**	**55**	1	2	3	58

TABLE A.5.6.4 BETWEEN-GROUPS SIGNIFICANT DIFFERENCES IN ABSOLUTE MEANS FOR EACH VARIABLE, p<.0001: [ANOVA Scheffe's Test Results]

s = significantly smaller than at least 1 other group in that variable.
g = significantly greater than at least 1 other group in that variable.
gs= significantly greater than at least 1 other group in that variable.
sg= significantly less than at least 1 other group in that variable.
s*= sig.less than all other 5 geographically distinct large sample groups.
g*= sig.greater than all other 5 geographically distinct large sample gps.
G*= sig.greater than all other 10 groups. (# no sig.diff.at p < .001)

	In	cr	ea	si	ng		Cr.	si	ze	--	->
VAR.	AND	BUS	VED	GAB	TAS	NEW	AUS	CHI	POU	ESK	FUE
QGAP	s	s	s	s	g	g	g	gs	gs	g	g
QGML	s	s	s	s	g	g	g	g	g	g	g
GFD	s	s		s		s	s	g	g	s	
QGFA	s	s				g	g	g	gs	g	g
QGFV	s	s	s	s	g	g	g	g	g	g	g
TSQH	s	s	s	s	s	gs	s	g	g	g	g
MPL	s	s	s	s	s	g	g	g	g	s	g
LMPW	s	s	s	s	s	sg	s	g	g	s	g
MPD	s			s		g	g	g	g		g
MPV	s	s	s	s	s	g	g	g	g	s	g
BANT #											
FPOST		g				s					
PPL	s*	g		g	s	s	g	g	g	g	g
TPL	s	s	s	sg	s	s	gs	sg	s	gs	G*
TPH	s	s	s	gs	s	gs	s	g	g	gs	g
QTTHK	s*	s	sg	sg	s	sg	gs	sg	sg	G*	sg
TIND	g		s	s	g	g	s	g	g	s	g
MANG	g	s		g		s	s	g	s	s	
MSCANG	g		g	g		s	gs	g	g	s*	
QSCANG	gs	s	s	sg	g	gs	s	gs	s	g*	g
EANG #											
PANGS	g	s		s	g		s	g	g	g	
TANGS			s	s		s		s	s	g	
PTANG		s					s	g	g		
ATANGS	s	g	s	g		s	gs	s	s	g	s

TABLE A.5.7

CORRELATION OF 29 NON-TEMPORAL VARIABLES WITH CRANIAL SIZE MEANS, 11 CASES (GROUPS)

(2-tailed Significance)

CRANIAL SIZE = [Cub.Root (GOL x AUB x BBH)]/100

CORRELATION OF NON-TEMPORAL VARIABLES WITH CRANIAL SIZE FOR TOTAL COMBINED SAMPLE.			
VARIABLE	POSITIVE COR.COEF.	SIG. p<.001	NO.of CASES
AUB	.874	.000	444
ZYB	.869	.000	442
GOL	.862	.000	444
SCB	.832	.000	444
BBH	.807	.000	444
NLH	.723	.000	443
ASB	.705	.000	444
OCA	.668	.000	444
FRA	.642	.000	444
PAA	.621	.000	444
WCB	.599	.000	444
FML	.588	.000	443
NLA	.585	.000	443
SPHO	.561	.000	443
SCXCB	.559	.000	444
XCB	.551	.000	444
FMB	.521	.000	444
INOP	.483	.000	444
LINC	.438	.000	444
NLB	.193	.000	443
VARIABLE	NEGATIVE CORR.COEF.	SIG. p<.001	CASES
NBHIDX	-.363	.000	443
ENINA	-.346	.000	444
OCCOCA	-.332	.000	444
BANG	-.290	.000	442
VARIABLE	NEGLIGIBLE CORRELATION	SIG. p>.001	CASES
OIX	-.130	.006	444
FANG	-.090	.058	442
ENOP	.086	.069	444
SCBGOL	.065	.169	444
OCNINA	-.016	.743	443

CORRELATION OF NON-TEMPORAL VARIABLE GROUP MEANS WITH CRANIAL SIZE GROUP MEANS.			
VARIABLE	POSITIVE COR.COEF.	SIG. p<.001	NO.of CASES
AUB	.952	.000	11
ZYB	.965	.000	11
GOL	.876	.000	11
SCB	.930	.000	11
BBH	.848	.001	11
NLH	.891	.000	11
ASB	.797	.003	11
OCA	.933	.000	11
FRA	.577	.063	11
PAA	.707	.015	11
WCB	.816	.002	11
FML	.671	.024	11
NLA	.727	.011	11
SPHO	.793	.004	11
SCXCB	.801	.003	11
XCB	.558	.074	11
FMB	.946	.000	11
INOP	.887	.000	11
LINC	.665	.026	11
VARIABLE	NEGATIVE CORR.COEF.	SIG. p<.001	CASES
NBHIDX	-.676	.022	11
ENIN	-.876	.000	11
OCCOCA	-.529	.094	11
VARIABLE	NEGLIGIBLE CORRELATION	SIG. p>.1	CASES
BANG	-.496	.121	11
OIX	-.460	.155	11
FANG	-.490	.126	11
ENOP	-.023	.948	11
SCBGOL	.384	.244	11
OCNINA	-.419	.200	11
NLB	-.152	.655	11

TABLES A.5.8.1-3

ONEWAY ANALYSIS OF VARIANCE of 29 NON-TEMPORAL VARIABLES in 11 GROUPS. RESULTS OF SCHEFFES'S TEST.

Each number in the tables refers to the number of variables which Scheffe's test shows are significantly greater for the vertically named group than for the corresponding horizontally listed group. The groups are named with increasing cranial size from left to right and from top to bottom.

TABLE A.5.8.1 NO. OF LINEAR NON-TEMPORAL VARIABLES WITH SIGNIFICANT DIFFERENCE IN MEANS BETWEEN PAIRS OF GROUPS.

(21 linear variables are involved)

	AND	BUS	VED	GAB	TAS	NEW	AUS	CHI	POU	ESK	FUE
AND			1				1				
BUS	4		1							1	
VED	2										
GAB	7	3				1	1	1	2	2	1
TAS	7	1	1							1	
NEW	11	6	3	2					1	1	
AUS	15	8	4	2	1	2		1	1	1	1
CHI	18	10	10	9	2	5	6			2	
POU	16	10	9	10	2	7	5	2		1	
ESK	18	9	11	11	4	11	9	2	2		
FUE	18	11	9	12	5	9	7	3	1	2	

TABLE A.5.8.2 NO. OF NON-LINEAR NON-TEMPORAL VARIABLES WITH SIGNIFICANT DIFFERENCE IN MEANS BETWEEN PAIRS OF GROUPS

(2 Angular & 5 Ratio Variables are involved.)

	AND	BUS	VED	GAB	TAS	NEW	AUS	CHI	POU	ESK	FUE
AND		1	1		2	2	3	2	5	3	3
BUS	1				1			1	2	1	1
VED	1								4	1	1
GAB	2	1	1		2	2	1	4	4	3	2
TAS	2	1	1					1	2	1	1
NEW	2	1	1	1			1	2	4	1	1
AUS	2	1		1				1	3	1	1
CHI	1	2	1	1		1	1		1	2	
POU	1	2	1				1			1	
ESK	1	1	1	1			1	1	3		
FUE	1	1	1				1				

TABLE A.5.8.3 TOTAL NUMBER OF SIGNIFICANT DIFFERENCES IN NON-TEMPORAL VARIABLE GROUP MEANS FOR EACH OF 11 GROUPS.

	21 NON-LINEAR TEMP. VARS.			7 NON-NON-LINEAR TEMP. VARS.			28 N-T VARS.
GP	No.sig. smaller means	No.sig. larger means	No.sig. different means	No.sig. smaller means	No.sig. larger means	No.sig. different means	No.sig. different means
AND	116	2	118	14	22	36	154
BUS	60	6	66	11	7	18	84
VED	49	2	51	8	7	15	66
GAB	46	18	64	4	22	26	90
TAS	14	10	24	5	9	14	38
NEW	35	24	59	5	14	19	78
AUS	29	36	65	9	10	19	84
CHI	9	62	71	12	10	22	93
POU	7	62	69	28	6	34	103
ESK	11	77	88	14	9	23	111
FUE	2	77	79	10	4	14	93

TABLE A.6.1 VARIABLES USED IN FACTOR ANALYSIS

As a result of tests for normality prior to analysis of variance procedures, 13 of the variables involved in factor analysis have been transformed, as indicated in the table.

VAR. CODE	VARIABLE	TRANSFORMATION
ASB	BIASTERION CRANIAL BREADTH	
AUB	BIAURICULAR CRANIAL BREADTH	
BANT	BASION POSITION ANTERIOR TO BITYMPANIC LINE	
BANG	BASE FLEXION ANGLE	
BBH	BASION-BREGMA CRANIAL HEIGHT	
ENIN	ENDINION-INION SEPARATION	
EANG	EXTERNAL AUDITORY MEATUS AXIS ANGLE	
FANG	FORAMEN MAGNUM ANGLE	
L FML	FORAMEN MAGNUM LENGTH	LOG_{10}
L FMB	FORAMEN MAGNUM WIDTH	LOG_{10}
FRA	FRONTAL (NASION-BREGMA) ARC	
GOL	GLABELLA-OPISTHOCRANION CRANIAL LENGTH	
GFD	GLENOID FOSSA DEPTH	
Q GAP	GLENOID FOSSA ANTERIOR/POSTERIOR LENGTH	SQR
Q GML	GLENOID FOSSA MEDIAL/LATERAL WIDTH	SQR
L GFIDX	GLENOID FOSSA LENGTH/WIDTH RATIO	LOG_{10}
MANG	MASTOID PROCESS AXIS ANGLE	
MPL	MASTOID PROCESS LENGTH	
L MPW	MASTOID PROCESS WIDTH	LOG_{10}
MPD	MASTOID PROCESS DEPTH	
NLB	NASAL APERTURE WIDTH	
NBHX	NASAL WIDTH/HEIGHT RATIO	
OCA	LAMBDA-OPISTHION OCCIPITAL ARC	
L OIX	LAMBDA-INION/INION-OPISTHION CHORD RATIO	LOG_{10}
OCNINA	OPISTHOCRANION-INION ARC	
PAA	PARIETAL (BREGMA-LAMBDA) ARC	
PANGS	PETROUS PYRAMID SAGITTAL ANGLE	
PPL	PETROUS PYRAMID LENGTH	
PTANG	PETROUS PYRAMID/TYMPANIC PLATE ANGLE	
SPHO	STAPHYLION-HORMION LENGTH	
Q SMCANG	SUPRAMEATAL CREST ANGLE	SQR

TABLE A.6.1 VARIABLES USED IN FACTOR ANALYSIS (Contd)

VAR. CODE	VARIABLE	TRANSFORMATION
Q SMCXCB	BI S.CREST BREADTH/MAX.PARIETAL BREADTH RATIO	SQR
L SMCBGOL	CRANIAL BREADTH/LENGTH RATIO	LOG_{10}
TSQH	TEMPORAL SQUAMOUS HEIGHT	
TANGS	TYMPANIC PLATE SAGITTAL ANGLE	
ATANGS	TYMPANIC PLATE ANTERIOR SAGITTAL ANGLE	
Q TPL	TYMPANIC PLATE AXIS LENGTH	SQR
Q TPH	TYMPANIC PLATE HEIGHT	SQR
TIND	TYMPANIC PLATE LATERAL RIM INDENT	
Q TTHK	TYMPANIC PLATE LATERAL RIM THICKNESS	SQR
WCB	MINIMUM CRANIAL BREADTH	
XCB	MAXIMUM PARIETAL BREADTH	

TABLE A.6.2
CORRELATION MATRIX OF VARIABLES IN FACTOR ANALYSIS

11 GROUPS, 440 CASES. 2-tailed Signif: * p < .01 ** p < .001
3 cases have 1 missing variable each.

VARIABLES:	MPD	LMPW	MPL	QGAP	QGML	PPL
MPD	1.0000	.5773**	.6022**	.4203**	.4401**	.2910**
LMPW	.5773**	1.0000	.6396**	.3448**	.3731**	.3469**
MPL	.6022**	.6396**	1.0000	.3997**	.4342**	.3476**
QGAP	.4203**	.3448**	.3997**	1.0000	.5448**	.3144**
QGML	.4401**	.3731**	.4342**	.5448**	1.0000	.3070**
PPL	.2910**	.3469**	.3476**	.3144**	.3070**	1.0000
QTPL	.4194**	.3910**	.4262**	.4588**	.4961**	.3275**
QTPH	.1706**	.3517**	.3863**	.2611**	.2734**	.3012**
TSQH	.3184**	.3761**	.3323**	.4329**	.3405**	.3940**
QTTHK	.1492*	.0714	.2010**	.3908**	.2062**	.2365**
TIND	.0837	.1427*	.0601	.0111	.0470	-.0834
ATANGS	.0537	-.0788	-.0058	.0087	-.0537	.1029
BANT	-.0703	.0165	.0026	.1090	.0745	.1805**
TANGS	.3268**	-.0255	.0200	.0696	.0960	.0385
PTANG	-.2434**	-.0279	-.0701	-.0095	-.0189	-.1786**
PANGS	-.0004	-.0552	-.0693	.0496	.0603	-.1802**
MANG	-.1379*	-.1950**	-.3501**	-.1510*	-.0703	-.0292
EANG	-.0137	.0118	.0474	.0283	-.0515	-.0762
GFD	.2482**	.3496**	.3907**	.3399**	.3976**	.2224**
GOL	.4170**	.4450**	.4890**	.5581**	.4623**	.4675**
AUB	.5163**	.5271**	.5049**	.6168**	.6280**	.4640**
BBH	.3345**	.3783**	.4025**	.4748**	.4056**	.4679**
BANG	-.1558*	-.3054**	-.3000**	-.1530*	-.2586**	-.1502*
FANG	-.1765**	-.1264*	-.1593**	-.1453*	-.1081	.0460
LSCBGOL	.1782**	.1897**	.0968	.0643	.1960**	.0917
QSCXCB	.3651**	.2307**	.3278**	.4578**	.3604**	.3197**
OCNINA	-.0364	.0421	.1237*	-.1255*	-.1317*	.0131
LOIX	-.0735	-.0753	-.0388	-.1445*	-.1889**	-.0752
ENØIN	-.1605**	-.2369**	-.1468*	-.2262**	-.3066**	-.2425**
LGFIDX	.0183	.0035	.0023	.5447**	-.4057**	.0347
SPHO	.4409**	.5569**	.4474**	.4211**	.4480**	.3381**
LFML	.2137**	.2180**	.1972**	.3490**	.2983**	.4595**
LFMB	.2167**	.2397**	.2667**	.3418**	.3022**	.3594**
FRA	.2198**	.3269**	.3561**	.3803**	.3198**	.3543**
PAA	.2874**	.2592**	.3360**	.3392**	.2493**	.2840**
OCA	.3325**	.4275**	.4130**	.3998**	.3425**	.3369**
NBHX	-.0652	-.1223	-.1120	-.2305**	-.1988**	-.2236**
NLB	.2519**	.2378**	.2817**	.1969**	.2271**	.1541*
XCB	.3278**	.4833**	.3623**	.3002**	.3997**	.3380**
ASB	.4849**	.5037**	.5056**	.4623**	.4474**	.4192**
WCB	.4163**	.3969**	.4451**	.3928**	.3856**	.3696**
QSCANG	-.0490	-.1865**	-.2346**	.0336	-.1164	-.0497

VARIABLES:	QTPL	QTPH	TSQH	QTTHK	TIND	ATANGS
MPD	.4194**	.1706**	.3184**	.1492*	.0837	.0537
LMPW	.3910**	.3517**	.3761**	.0714	.1427*	-.0788
MPL	.4262**	.3863**	.3323**	.2010**	.0601	-.0058
QGAP	.4588**	.2611**	.4329**	.3908**	.0111	.0087
QGML	.4961**	.2734**	.3405**	.2062**	.0470	-.0537
PPL	.3275**	.3012**	.3940**	.2365**	-.0834	.1029
QTPL	1.0000	.3164**	.2728**	.3356**	-.1684**	.0684
QTPH	.3164**	1.0000	.2882**	.2243**	.0024	-.0643
TSQH	.2728**	.2882**	1.0000	.3334**	.0141	.0478
QTTHK	.3356**	.2243**	.3334**	1.0000	-.2832**	.3263**
TIND	-.1684**	.0024	.0141	-.2832**	1.0000	-.2962**
ATANGS	.0684	-.0643	.0478	.3263**	-.2962**	1.0000
BANT	.1457*	.0737	.0684	.2071**	-.1491*	-.0096
TANGS	.1291*	-.0700	.0444	.0927	.1160	.2858**
PTANG	-.1573**	.0897	.0678	-.0177	.0645	-.2173**
PANGS	-.0753	.0458	.1242*	.0612	.1797**	-.0055
MANG	-.0903	-.0034	-.0343	-.2385**	.0166	-.1011
EANG	-.0830	.1096	.1245*	-.1611**	.0568	-.1404*
GFD	.2527**	.3162**	.2488**	.1182	-.0574	-.1455*
GOL	.4277**	.2878**	.4948**	.5138**	-.0690	.2066**
AUB	.5542**	.3996**	.5619**	.3488**	.2782**	.0353

TABLE A.6.2 (Continued)

VARIABLES:	QTPL	QTPH	TSQH	QTTHK	TIND	ATANGS
BBH	.4083**	.3559**	.5183**	.3109**	-.1278*	.1476*
BANG	-.0816	-.2816**	-.2591**	-.0023	-.1357*	.1409*
FANG	-.0598	-.0089	-.1350*	-.1045	-.1678**	.0640
LSCBGOL	.1209	.1895**	.1453*	-.1714**	.4041**	-.1270*
QSCXCB	.2853**	.2069**	.4032**	.4233**	.0398	.1335*
OCNINA	-.0010	.0760	-.0066	-.1218	-.0827	.0215
LOIX	-.1019	-.0184	-.0362	-.1345*	.1011	.0603
ENØIN	-.1724**	-.1428*	-.1872**	-.2494**	-.0357	.0364
LGFIDX	.0031	.0108	.1272*	.2196**	-.0353	.0634
SPHO	.3523**	.3115**	.3838**	.1734**	.1385*	-.0209
LFML	.2758**	.2434**	.3945**	.3730**	-.0472	.2377**
LFMB	.2634**	.0888	.3131**	.2363**	.0353	.0957
FRA	.3089**	.1611**	.3378**	.3813**	-.0730	.1453*
PAA	.2447**	.2169**	.4296**	.2482**	-.0848	.1067
OCA	.3102**	.3336**	.4519**	.3257**	.0587	.0784
NBHX	-.1080	-.2218**	-.3743**	-.2748**	-.0527	-.0869
NLB	.2236**	.0805	.0072	-.0252	-.0184	-.0778
XCB	.3473**	.3281**	.3495**	.0542	.2680**	-.0037
ASB	.3839**	.3512**	.3952**	.3037**	.0955	.1041
WCB	.4069**	.3030**	.3681**	.2163**	.1200	-.0338
QSCANG	.0155	-.0380	.1023	.1377*	.1308*	.0971

VARIABLES:	BANT	TANGS	PTANG	PANGS	MANG	EANG
MPD	-.0703	.3268**	-.2434**	-.0004	-.1379*	-.0137
LMPW	.0165	-.0255	-.0279	-.0552	-.1950**	.0118
MPL	.0026	.0200	-.0701	-.0693	-.3501**	.0474
QGAP	.1090	.0696	-.0095	.0496	-.1510*	.0283
QGML	.0745	.0960	-.0189	.0603	-.0703	-.0515
PPL	.1805**	.0385	-.1786**	-.1802**	-.0292	-.0762
QTP	.1457*	.1291*	-.1573**	-.0753	-.0903	-.0830
QTPH	.0737	-.0700	.0897	.0458	-.0034	.1096
TSQH	.0684	.0444	.0678	.1242*	-.0343	.1245*
QTTHK	.2071**	.0927	-.0177	.0612	-.2385**	-.1611**
TIND	-.1491*	.1160	.0645	.1797**	.0166	.0568
ATANGS	-.0096	.2858**	-.2173**	-.0055	-.1011	-.1404*
BANT	1.0000	-.4484**	.1788**	-.1788**	.0894	-.0891
TANGS	-.4484**	1.0000	-.5721**	.2002**	-.1167	-.0417
PTANG	.1788**	-.5721**	1.0000	.6877**	.0518	.0894
PANGS	-.1788**	.2002**	.6877**	1.0000	-.0381	.0738
MANG	.0894	-.1167	.0518	-.0381	1.0000	-.0220
EANG	-.0891	-.0417	.0894	.0738	-.0220	1.0000
GFD	.0446	-.1255*	.1562*	.0737	-.0544	.0912
GOL	.1352*	.0888	-.0278	.0447	-.3040**	-.0639
AUB	.0726	.1818**	.0849	.2627**	-.0905	-.0763
BBH	.0870	.0347	-.0011	.0303	-.0700	.0378
BANG	-.1833**	.0425	-.1752**	-.1722**	.0304	-.0827
FANG	-.0572	-.0839	-.0793	-.1673**	.1597**	-.0661
LSCBGOL	-.1189	.1645**	.0664	.2255**	.1870**	-.0836
QSCXCB	.0464	.1972**	-.0989	.0533	-.2012**	-.0130
OCNINA	.0127	-.1526*	.0104	-.1256*	-.0211	.1170
LOIX	-.1918**	.0838	-.0260	.0382	-.0234	-.0205
ENIN	-.1147	.0003	-.0394	-.0497	.0880	.0490
LGFIDX	.0429	-.0217	.0086	-.0077	-.0957	.0806
SPHO	-.0182	.0811	.0149	.0890	-.1016	.0388
LFML	.1691**	.1094	-.0102	.0847	-.0343	-.0707
LFMB	.0422	.0791	.0360	.1137	-.1285*	.0131
FRA	.2046**	-.0429	.0797	.0578	-.2817**	-.0577
PAA	.1290*	.0547	.0092	.0602	-.1556*	.0959
OCA	.0371	.0866	.0604	.1469*	-.2301**	-.0016
NBHX	-.0714	-.0547	-.1588**	-.2436**	-.0806	.0317
NLB	.0440	-.0387	-.1636**	-.2346**	-.1367*	.0284
XCB	-.0043	.0875	.1170	.2192**	.0043	-.1323*
ASB	-.0694	.2021**	-.0690	.0948	-.2205**	-.1234*
WCB	.0612	.0607	.0166	.0761	-.0495	-.0812
QSCANG	.0446	.1795**	-.0029	.1559*	.1949**	-.0513

TABLE A.6.2 (Continued)

VARIABLES:	GFD	GOL	AUB	BBH	BANG	FANG
MPD	.2482**	.4170**	.5163**	.3345**	-.1558*	-.1765**
LMPW	.3496**	.4450**	.5271**	.3783**	-.3054**	-.1264*
MPL	.3907**	.4890**	.5049**	.4025**	-.3000**	-.1593**
QGAP	.3399**	.5581**	.6168**	.4748**	-.1530*	-.1453*
QGML	.3976**	.4623**	.6280**	.4056**	-.2586**	-.1081
PPL	.2224**	.4675**	.4640**	.4679**	-.1502*	.0460
QTPL	.2527**	.4277**	.5542**	.4083**	-.0816	-.0598
QTPH	.3162**	.2878**	.3996**	.3559**	-.2816**	-.0089
TSQH	.2488**	.4948**	.5619**	.5183**	-.2591**	-.1350*
QTTHK	.1182	.5138**	.3488**	.3109**	-.0023	-.1045
TIND	-.0574	-.0690	.2782**	-.1278*	-.1357*	-.1678**
ATANGS	-.1455*	.2066**	.0353	.1476*	.1409*	.0640
BANT	.0446	.1352*	.0726	.0870	-.1833**	-.0572
TANGS	-.1255*	.0888	.1818**	.0347	.0425	-.0839
PTANG	.1562*	-.0278	.0849	-.0011	-.1752**	-.0793
PANGS	.0737	.0447	.2627**	.0303	-.1722**	-.1673**
MANG	-.0544	-.3040**	-.0905	-.0700	.0304	.1597**
EANG	.0912	-.0639	-.0763	.0378	-.0827	-.0661
GFD	1.0000	.3310**	.3248**	.2424**	-.3042**	-.1318*
GOL	.3310**	1.0000	.6448**	.5661**	-.2109**	-.2296**
AUB	.3248**	.6448**	1.0000	.5402**	-.2776**	-.2153**
BBH	.2424**	.5661**	.5402**	1.0000	-.2456**	.2697**
BANG	-.3042**	-.2109**	-.2776**	-.2456**	1.0000	.1213
FANG	-.1318*	-.2296**	-.2153**	.2697**	.1213	1.0000
LSCBGOL	.0593	-.3001**	.4183**	-.0183	-.1511*	-.0441
QSCXCB	.1836**	.5166**	.5600**	.3221**	-.0120	-.1315*
OCNINA	.0559	.0276	-.1372*	.1026	-.0504	.0798
LOIX	-.1395*	-.1326*	-.1154	-.0872	.1257*	-.0296
ENØIN	-.2054**	-.3739**	-.3326**	-.1571**	.1212	.0698
LGFIDX	-.0238	.1473*	.0427	.1129	.0914	-.0507
SPHO	.3600**	.5015**	.5437**	.3795**	-.3143**	-.3095**
LFML	.2003**	.5673**	.5116**	.4171**	-.1244*	-.0641
LFMB	.2337**	.4852**	.4882**	.3679**	-.0894	-.1503*
FRA	.2687**	.7123**	.4290**	.5415**	-.2210**	-.1780**
PAA	.2576**	.6153**	.3949**	.6086**	-.2435**	-.1092
OCA	.2483**	.7152**	.5458**	.4400**	-.2975**	-.3225**
NBHX	-.1324*	-.2939**	-.3857**	-.2294**	.2907**	.1328*
NLB	.1367*	.1712**	.1332*	.1944**	.0654	.0018
XCB	.2733**	.3996**	.6413**	.3432**	-.3669**	-.1876**
ASB	.3164**	.6924**	.6807**	.4115**	-.2641**	-.2220**
WCB	.2990**	.4708**	.6289**	.4054**	-.2437**	-.1510*
QSCANG	-.2180**	-.1097	.1324*	-.0054	.1832**	-.0137

VARIABLES:	LSMCBGOL	QSMCXCB	OCNINA	LOIX	ENØIN	LGFIDX
MPD	.1782**	.3651**	-.0364	-.0735	-.1605**	.0183
LMPW	.1897**	.2307**	.0421	-.0753	-.2369**	.0035
MPL	.0968	.3278**	.1237*	-.0388	-.1468*	.0023
QGAP	.0643	.4578**	-.1255*	-.1445*	-.2262**	.5447**
QGML	.1960**	.3604**	-.1317*	-.1889**	-.3066**	-.4057**
PPL	.0917	.3197**	.0131	-.0752	-.2425**	.0347
QTPL	.1209	.2853**	-.0010	-.1019	-.1724**	.0031
QTPH	.1895**	.2069**	.0760	-.0184	-.1428*	.0108
TSQH	.1453*	.4032**	-.0066	-.0362	-.1872**	.1272*
QTTHK	-.1714**	.4233**	-.1218	-.1345*	-.2494**	.2196**
TIND	.4041**	.0398	-.0827	.1011	-.0357	-.0353
ATANGS	-.1270*	.1335*	.0215	.0603	.0364	.0634
BANT	-.1189	.0464	.0127	-.1918**	-.1147	.0429
TANGS	.1645**	.1972**	-.1526*	.0838	.0003	-.0217
PTANG	.0664	-.0989	.0104	-.0260	-.0394	.0086
PANGS	.2255**	.0533	-.1256*	.0382	-.0497	-.0077
MANG	.1870**	-.2012**	-.0211	-.0234	.0880	-.0957
EANG	-.0836	-.0130	.1170	-.0205	.0490	.0806
GFD	.0593	.1836**	.0559	-.1395*	-.2054**	-.0238

TABLE A.6.2 (Continued)

VARIABLES:	LSMCBGOL	QSMCXCB	OCNINA	LOIX	ENØIN	LGFIDX
GOL	-.3001**	.5166**	.0276	-.1326*	-.3739**	.1473*
AUB	.4183**	.5600**	-.1372*	-.1154	-.3326**	.0427
BBH	-.0183	.3221**	.1026	-.0872	-.1571**	.1129
BANG	-.1511*	-.0120	-.0504	.1257*	.1212	.0914
FANG	-.0441	-.1315*	.0798	-.0296	.0698	-.0507
LSCBGOL	1.0000	.1418*	-.1087	.0466	.0158	-.1275*
QSCXCB	.1418*	1.0000	-.2470**	-.1721**	-.3304**	.1383*
OCNINA	-.1087	-.2470**	1.0000	.3866**	.3419**	-.0035
LOIX	.0466	-.1721**	.3866**	1.0000	.6232**	.0316
ENIN	.0158	-.3304**	.3419**	.6232**	1.0000	.0607
LGFIDX	-.1275*	.1383*	-.0035	.0316	.0607	1.0000
SPHO	.1149	.3454**	-.0489	-.0842	-.2893**	.0117
LFML	.0049	.3734**	-.0961	.0735	-.2158**	.0809
LFMB	.0280	.3516**	-.0034	-.0588	-.2066**	.0730
FRA	-.2529**	.1994**	.1267*	-.1270*	-.2246**	.0974
PAA	-.1719**	.3267**	.2070**	-.1541*	-.1130	.1211
OCA	-.0895	.3057**	.0112	.0472	-.3104**	.0940
NBHX	-.1116	-.1614**	.1487*	.0491	.1855**	-.0490
NLB	-.0300	.1936**	.1489*	-.0652	-.0362	-.0104
XCB	.4860**	-.1218	.1368*	.0390	-.1264*	-.0721
ASB	.1929**	.4640**	.0372	-.0384	-.2727**	.0596
WCB	.2041**	.2882**	.0233	-.0433	-.1895**	.0413
QSCANG	.2657**	.2263**	-.1874**	.0355	.0177	.1506*

VARIABLES:	SPHO	LFML	LFMB	FRA	PAA	OCA
MPD	.4409**	.2137**	.2167**	.2198**	.2874**	.3325**
LMPW	.5569**	.2180**	.2397**	.3269**	.2592**	.4275**
MPL	.4474**	.1972**	.2667**	.3561**	.3360**	.4130**
QGAP	.4211**	.3490**	.3418**	.3803**	.3392**	.3998**
QGML	.4480**	.2983**	.3022**	.3198**	.2493**	.3425**
PPL	.3381**	.4595**	.3594**	.3543**	.2840**	.3369**
QTPL	.3523**	.2758**	.2634**	.3089**	.2447**	.3102**
QTPH	.3115**	.2434**	.0888	.1611**	.2169**	.3336**
TSQH	.3838**	.3945**	.3131**	.3378**	.4296**	.4519**
QTTHK	.1734**	.3730**	.2363**	.3813**	.2482**	.3257**
TIND	.1385*	-.0472	.0353	-.0730	-.0848	.0587
ATANGS	-.0209	.2377**	.0957	.1453*	.1067	.0784
BANT	-.0182	.1691**	.0422	.2046**	.1290*	.0371
TANGS	.0811	.1094	.0791	-.0429	.0547	.0866
PTANG	.0149	-.0102	.0360	.0797	.0092	.0604
PANGS	.0890	.0847	.1137	.0578	.0602	.1469*
MANG	-.1016	-.0343	-.1285*	-.2817**	-.1556*	-.2301**
EANG	.0388	-.0707	.0131	-.0577	.0959	-.0016
GDL	.3600**	.2003**	.2337**	.2687**	.2576**	.2483**
GOL	.5015**	.5673**	.4852**	.7123**	.6153**	.7152**
AUB	.5437**	.5116**	.4882**	.4290**	.3949**	.5458**
BBH	.3795**	.4171**	.3679**	.5415**	.6086**	.4400**
BANG	-.3143**	-.1244*	-.0894	-.2210**	-.2435**	-.2975**
FANG	-.3095**	-.0641	-.1503*	-.1780**	-.1092	-.3225**
LSCBGOL	.1149	.0049	.0280	-.2529**	-.1719**	-.0895
QSCXCB	.3454**	.3734**	.3516**	.1994**	.3267**	.3057**
OCNINA	-.0489	-.0961	-.0034	.1267*	.2070**	.0112
LOIX	-.0842	.0735	-.0588	-.1270*	-.1541*	.0472
ENØIN	-.2893**	-.2158**	-.2066**	-.2246**	-.1130	-.3104**
LGFIDX	.0117	.0809	.0730	.0974	.1211	.0940
SPHO	1.0000	.3163**	.3154**	.3007**	.3413**	.4702**
LFML	.3163**	1.0000	.5679**	.3765**	.3307**	.3316**
LFMB	.3154**	.5679**	1.0000	.3550**	.2888**	.2994**
FRA	.3007**	.3765**	.3550**	1.0000	.4205**	.4192**
PAA	.3413**	.3307**	.2888**	.4205**	1.0000	.3033**
OCA	.4702**	.3316**	.2994**	.4192**	.3033**	1.0000
NBHX	-.1884**	-.3589**	-.2820**	-.1523*	-.1569**	-.2886**
NLB	.2117**	-.0447	.0542	.1350*	.1511*	.0506
XCB	.3817**	.3249**	.2716**	.3873**	.2518**	.4569**
ASB	.4991**	.4479**	.4110**	.4408**	.4101**	.5685**
WCB	.3855**	.4160**	.3636**	.3865**	.2699**	.3862**
QSCANG	-.0552	.0794	-.0286	-.1679**	-.1028	-.0087

TABLE A.6.2 (Continued)

VARIABLES:	NBHX	NLB	XCB	ASB	WCB	QSMCANG
MPD	-.0652	.2519**	.3278**	.4849**	.4163**	-.0490
LMPW	-.1223	.2378**	.4833**	.5037**	.3969**	-.1865**
MPL	-.1120	.2817**	.3623**	.5056**	.4451**	-.2346**
QGAP	-.2305**	.1969**	.3002**	.4623**	.3928**	.0336
QGML	-.1988**	.2271**	.3997**	.4474**	.3856**	-.1164
PPL	-.2236**	.1541*	.3380**	.4192**	.3696**	-.0497
QTPL	-.1080	.2236**	.3473**	.3839**	.4069**	.0155
QTPH	-.2218**	.0805	.3281**	.3512**	.3030**	-.0380
TSQH	-.3743**	.0072	.3495**	.3952**	.3681**	.1023
QTTHK	-.2748**	-.0252	.0542	.3037**	.2163**	.1377*
TIND	-.0527	-.0184	.2680**	.0955	.1200	.1308*
ATANGS	-.0869	-.0778	-.0037	.1041	-.0338	.0971
BANT	-.0714	.0440	-.0043	-.0694	.0612	.0446
TANGS	-.0547	-.0387	.0875	.2021**	.0607	.1795**
PTANG	-.1588**	-.1636**	.1170	-.0690	.0166	-.0029
PANGS	-.2436**	-.2346**	.2192**	.0948	.0761	.1559*
MANG	-.0806	-.1367*	.0043	-.2205**	-.0495	.1949**
EANG	.0317	.0284	-.1323*	-.1234*	-.0812	-.0513
GFD	-.1324*	.1367*	.2733**	.3164**	.2990**	-.2180**
GOL	-.2939**	.1712**	.3996**	.6924**	.4708**	-.1097
AUB	-.3857**	.1332*	.6413**	.6807**	.6289**	.1324*
BBH	-.2294**	.1944**	.3432**	.4115**	.4054**	-.0054
BANG	.2907**	.0654	-.3669**	-.2641**	-.2437**	.1832**
FANG	.1328*	.0018	-.1876**	-.2220**	-.1510*	-.0137
LSCBGOL	-.1116	-.0300	.4860**	.1929**	.2041**	.2657**
QSCXCB	-.1614**	.1936**	-.1218	.4640**	.2882**	.2263**
OCNINA	.1487*	.1489*	.1368*	.0372	.0233	-.1874**
LOIX	.0491	-.0652	.0390	-.0384	-.0433	.0355
ENDIN	.1855**	-.0362	-.1264*	-.2727**	-.1895**	.0177
LGFIDX	-.0490	-.0104	-.0721	.0596	.0413	.1506*
SPHO	-.1884**	.2117**	.3817**	.4991**	.3855**	-.0552
LFML	-.3589**	-.0447	.3249**	.4479**	.4160**	.0794
LFMB	-.2820**	.0542	.2716**	.4110**	.3636**	-.0286
FRA	-.1523*	.1350*	.3873**	.4408**	.3865**	-.1679**
PAA	-.1569**	.1511*	.2518**	.4101**	.2699**	-.1028
OCA	-.2886**	.0506	.4569**	.5685**	.3862**	-.0087
NBHX	1.0000	.6873**	-.2934**	-.2333**	-.2586**	-.1182
NLB	.6873**	1.0000	.0031	.1731**	.1502*	-.1668**
XCB	-.2934**	.0031	1.0000	.5675**	.4703**	-.0642
ASB	-.2333**	.1731**	.5675**	1.0000	.4416**	-.0573
WCB	-.2586**	.1502*	.4703**	.4416**	1.0000	.0390
QSCANG	-.1182	-.1668**	-.0642	-.0573	.0390	1.0000

TABLE A.6.3
SUITABILITY TESTS FOR FACTOR ANALYSIS. -- ANALYSES 1-6

FUNCTION ANALYSIS	KMO SAMPLING ADEQUACY	BARTLETT TEST OF SPHERICITY	OFF DIAGONAL ELEMENTS IN AIC > .09		RESIDUALS IN R.C.MATRIX >.05	
1	.643	4885.3 sig. .00000	52	17%	70,	45%
2	.746	6310.1 sig. .00000	46	11%	74	35%
3	.737	6679.8 sig. .00000	52	10.3%	99	39%
4	.628	5642.5 sig. .00000	80	14.5%	95	34%
5	.777	7643.6 sig. .00000	50	7.1%	110	31%
6	.750	14419.6 sig. .00000	64	4.3%	177	23%

Summary of the results of 4 tests to assess the suitability for factor analysis of the data in each of 6 analyses.
The results indicate that for each analysis:

* Sampling is adequate for factor analysis since the KMO (Kaiser-Meyer-Olkin) value is >.60.

* Multivariate normality in the data is verified by high test statistic values and low significance levels in the Bartlett Test for Sphericity.

* Correlation between factors is small since the percentage of off-diagonal elements > 0.09 in the AIC (Anti-Image Correlation) Matrix is small (17% or less).

* Observed correlations are satisfactorily reproduced by the fitted model since the percentage of residuals > 0.05 in the Reproduced Correlation (R.C.) Matrix is sufficiently low (45% or less).

(Norusis, 1993:50-53,59; Tabachick & Fidell, 1989:604,639).

TABLE A.6.4 ANALYSIS No.5 CORRELATION MATRIX:

	MPD	LMPW	MPL	QGAP	QGML	TSQH	PPL
MPD	1.00000						
LMPW	.57729	1.00000					
MPL	.60221	.63957	1.00000				
QGAP	.42029	.34476	.39972	1.00000			
QGML	.44014	.37310	.43418	.54478	1.00000		
TSQH	.31841	.37608	.33231	.43289	.34055	1.00000	
PPL	.29097	.34689	.34762	.31439	.30697	.39397	1.00000
QTPL	.41944	.39104	.42622	.45877	.49606	.27275	.32752
QTPH	.17062	.35169	.38627	.26112	.27336	.28817	.30119
TIND	.08371	.14268	.06008	.01115	.04701	.01413	-.08343
QTTHK	.15052	.07294	.20203	.39392	.21515	.33546	.23973
ATANGS	.05371	-.07879	-.00581	.00871	-.05365	.04782	.10287
PANGS	-.00039	-.05517	-.06933	.04960	.06030	.12418	-.18021
PTANG	-.24336	-.02790	-.07010	-.00946	-.01888	.06778	-.17858
TANGS	.32684	-.02548	.01996	.06957	.09599	.04441	.03847
BANT	-.07032	.01645	.00264	.10897	.07451	.06841	.18046
MANG	-.13788	-.19505	-.35014	-.15104	-.07034	-.03426	-.02919
EANG	-.01371	.01177	.04741	.02833	-.05154	.12454	-.07624
GOL	.41704	.44503	.48905	.55814	.46227	.49479	.46750
AUB	.51634	.52706	.50487	.61681	.62804	.56193	.46397
BBH	.33451	.37825	.40247	.47476	.40557	.51829	.46786
BANG	-.15579	-.30541	-.30002	-.15297	-.25864	-.25913	-.15020
FANG	-.17653	-.12642	-.15929	-.14526	-.10809	-.13502	.04599
LFML	.21368	.21798	.19720	.34905	.29833	.39452	.45947
LFMB	.21673	.23972	.26669	.34180	.30221	.31314	.35937
XCB	.32785	.48334	.36229	.30019	.39970	.34946	.33798
NLB	.25191	.23781	.28173	.19687	.22708	.00725	.15410

	QTPL	QTPH	TIND	QTTHK	ATANGS	PANGS	PTANG
QTPL	1.00000						
QTPH	.31642	1.00000					
TIND	-.16844	.00245	1.00000				
QTTHK	.34122	.22614	-.28311	1.00000			
ATANGS	.06838	-.06430	-.29618	.32539	1.00000		
PANGS	-.07529	.04578	.17965	.05509	-.00555	1.00000	
PTANG	-.15730	.08967	.06451	-.02567	-.21732	.68773	1.00000
TANGS	.12906	-.07001	.11602	.09652	.28576	.20025	-.57211
BANT	.14569	.07373	-.14909	.20739	-.00964	-.17882	.17884
MANG	-.09025	-.00338	.01660	-.23873	-.10110	-.03811	.05176
EANG	-.08298	.10960	.05683	-.16425	-.14039	.07384	.08945
GOL	.42768	.28781	-.06897	.51429	.20655	.04466	-.02776
AUB	.55416	.39965	.27823	.35369	.03529	.26269	.08490
BBH	.40833	.35587	-.12779	.31195	.14765	.03030	-.00110
BANG	-.08164	-.28160	-.13570	-.01114	.14092	-.17220	-.17522
FANG	-.05975	-.00893	-.16781	-.10386	.06405	-.16734	-.07930
LFML	.27585	.24344	-.04724	.37551	.23769	.08467	-.01020
LFMB	.26338	.08875	.03527	.23543	.09567	.11367	.03604
XCB	.34729	.32807	.26805	.05559	-.00368	.21924	.11702
NLB	.22357	.08046	-.01841	-.02653	-.07776	-.23456	-.16362

	TANGS	BANT	MANG	EANG	GOL	AUB	BBH
TANGS	1.00000						
BANT	-.44837	1.00000					
MANG	-.11667	.08937	1.00000				
EANG	-.04172	-.08909	-.02203	1.00000			
GOL	.08877	.13525	-.30400	-.06389	1.00000		
AUB	.18183	.07258	-.09045	-.07629	.64483	1.00000	
BBH	.03472	.08700	-.06997	.03783	.56609	.54017	1.00000
BANG	.04250	-.18326	.03037	-.08270	-.21093	-.27756	-.24559
FANG	-.08391	-.05715	.15966	-.06613	-.22958	-.21531	.26973
LFML	.10942	.16913	-.03431	-.07070	.56726	.51158	.41707
LFMB	.07911	.04219	-.12846	.01308	.48525	.48819	.36790
XCB	.08750	-.00430	.00430	-.13231	.39958	.64133	.34324
NLB	-.03873	.04401	-.13672	.02840	.17117	.13317	.19437

	BANG	FANG	LFML	LFMB	XCB	NLB
BANG	1.00000					
FANG	.12128	1.00000				
LFML	-.12437	-.06409	1.00000			
LFMB	-.08940	-.15035	.56791	1.00000		
XCB	-.36687	-.18757	.32489	.27157	1.00000	
NLB	.06542	.00184	-.04466	.05422	.00306	1.00000

Bartlett Test of Sphericity = 7643.6, Significance = .00000

TABLE A.6.5

ANALYSIS No.5. ANTI-IMAGE CORRELATION MATRIX Measures of sampling adequacy (MSA) are printed on the diagonal.
There are 50 (7.1%) off-diagonal elements of AIC Matrix > 0.09

Kaiser-Meyer-Olkin Measure of Sampling Adequacy = .77655

	MPD	LMPW	MPL	QGAP	QGML	TSQH	PPL
MPD	**.87416**						
LMPW	-.32430	**.90711**					
MPL	-.36558	-.19326	**.87832**				
QGAP	-.10362	.05533	.03286	**.94249**			
QGML	-.07559	.09257	-.05920	-.18975	**.92531**		
TSQH	-.00228	-.10424	.02089	-.03719	.03175	**.89362**	
PPL	.00818	-.00803	-.05710	.05741	.05291	-.10684	**.92874**
QTPL	-.01097	-.07519	-.07701	-.04168	-.10820	.12133	.08761
QTPH	.16620	-.09401	-.20129	.03029	.02213	.06148	-.08382
TIND	.05739	-.02671	-.03167	.02542	.12883	.08081	.14702
QTTHK	.04831	.12448	-.02310	-.14545	.07402	-.14787	.05073
ATANGS	.02192	.03432	-.06149	.09590	.10317	.04914	.04642
PANGS	-.07727	-.01731	.08243	.01820	.03161	-.06095	.06309
PTANG	.07796	.02520	-.07512	-.01330	-.02791	.06283	-.04402
TANGS	.04562	.04184	-.05807	-.00913	-.02845	.06592	-.05341
BANT	-.05429	.08050	.12123	.00106	.01975	.07503	-.12616
MANG	-.15968	.11950	.30604	.03948	-.02842	-.08555	-.02286
EANG	.01139	.01426	-.04185	-.09723	.03121	-.18394	.02678
GOL	-.00996	-.08323	-.03642	-.10059	-.04423	-.00745	-.06429
AUB	-.07823	-.08277	-.03688	-.20265	-.26980	-.20727	-.15859
BBH	-.02489	.02324	-.04638	-.11564	.02833	-.24921	-.05706
BANG	-.07205	.10132	.16283	-.03092	.14350	.06275	-.01861
FANG	.07747	-.04192	.04962	.04801	-.04884	.15581	-.09996
LFML	-.01309	.01626	.10223	.01508	.00105	-.05043	-.13825
LFMB	.09045	-.00167	-.07349	.00129	.00015	.07336	-.08770
XCB	.06860	-.17482	.01214	.06019	-.02045	.02662	-.10077
NLB	-.06581	-.04991	-.04928	-.03291	-.09636	.11257	-.04119

	QTPL	QTPH	TIND	QTTHK	ATANGS	PANGS	PTANG
QTPL	**.87278**						
QTPH	-.06369	**.83715**					
TIND	.35205	.05527	**.48987**				
QTTHK	-.08529	-.16912	.18848	**.81292**			
ATANGS	.09828	.09511	.24196	-.15455	**.73990**		
PANGS	.04952	-.02561	.02065	-.01472	-.01662	**.30746**	
PTANG	-.03675	.02494	-.01179	.01248	.02018	-.99770	**.35295**
TANGS	-.05223	.02883	-.02513	.00694	-.00404	-.99454	.99640
BANT	-.15218	.07596	-.01067	-.14769	-.07448	-.09557	.10347
MANG	-.01229	-.11324	.05348	.16745	.01716	-.00252	.00952
EANG	-.03565	-.16877	-.06773	.18995	.02556	-.09164	.08512
GOL	.06594	.06214	.07836	-.21828	-.07964	.00335	.00186
AUB	-.30834	-.12217	-.49137	-.12537	-.04673	-.02800	.00404
BBH	-.03586	-.07519	.12776	.03343	-.06963	.01064	-.01412
BANG	-.12877	.10496	.02569	-.05778	-.12032	-.02307	.03230
FANG	-.01931	-.00327	-.01316	.02228	-.04656	-.05387	.05889
LFML	.06489	-.12103	.02716	-.03869	-.10942	.05311	-.05278
LFMB	-.01345	.20505	.02463	.04488	.03887	-.04702	.04501
XCB	-.11133	-.06269	-.09398	.19554	-.09134	-.07301	.06661
NLB	-.03503	-.01432	-.00159	.12007	.05006	.07790	-.06852

	TANGS	BANT	MANG	EANG	GOL	AUB	BBH
TANGS	**.30809**						
BANT	.14413	**.64564**					
MANG	.01907	-.04773	**.64258**				
EANG	.08614	.06108	.02659	**.41445**			
GOL	.00651	.03021	.21195	.03313	**.91573**		
AUB	.00126	-.06345	-.10855	.12605	-.12068	**.86541**	
BBH	-.01351	-.00570	-.03662	-.09795	-.26256	-.09632	**.84163**
BANG	.04331	.28294	.01180	.05207	.02436	-.10037	.12955
FANG	.06423	.13125	-.03828	.12596	.26433	.05880	-.54984
LFML	-.05889	-.13471	-.06852	-.00218	-.23501	-.07950	.02650
LFMB	.04849	.08535	.03631	-.06760	-.05250	-.15513	-.10955
XCB	.07137	.11519	-.06859	.19569	-.04172	-.24256	-.05894
NLB	-.06729	-.05067	.07163	-.02457	-.06043	-.02586	-.13404

	BANG	FANG	LFML	LFMB	XCB	NLB
BANG	**.77043**					
FANG	-.05642	**.48897**				
LFML	-.03149	-.08009	**.87495**			
LFMB	-.03594	.12225	-.38089	**.86048**		
XCB	.18863	.13268	-.04365	.06377	**.87984**	
NLB	-.14691	.04815	.12319	.00645	.09770	**.79675**

TABLE A.6.6
ANALYSIS No.5. REPRODUCED CORRELATION MATRIX:

	MPD	LMPW	MPL	QGAP	QGML
MPD	.63552*	.02519	.01202	-.01728	-.04889
LMPW	.55210	.67539*	-.03323	-.04062	-.07755
MPL	.59020	.67280	.74230*	-.04236	-.01658
QGAP	.43757	.38539	.44208	.62053*	-.02282
QGML	.48904	.45065	.45075	.56760	.61691*
TSQH	.29405	.37691	.37930	.41694	.34815
PPL	.30372	.37892	.34224	.34189	.32116
QTPL	.47577	.41109	.45714	.52393	.55538
QTPH	.25808	.44030	.43062	.25021	.28586
TIND	.15424	.17712	.04643	-.01966	.09924
QTTHK	.16296	.09439	.22678	.37413	.23625
ATANGS	.03048	-.12948	-.03672	.01764	-.07594
PANGS	-.05073	-.08284	-.08608	.11779	.10642
PTANG	-.30015	-.09450	-.12056	.06025	.03346
TANGS	.35011	.03459	.06697	.05328	.07684
BANT	-.16222	.05657	.03311	.09273	.06282
MANG	-.26126	-.21167	-.39071	-.18127	-.04991
EANG	-.04587	.06019	.10406	-.00058	-.13073
GOL	.44700	.44359	.51808	.58215	.47703
AUB	.54888	.53958	.51091	.63332	.66173
BBH	.34172	.38642	.40767	.49765	.45284
BANG	-.17554	-.43130	-.36760	-.07298	-.14398
FANG	-.17900	-.18186	-.21448	-.13255	-.08839
LFML	.18587	.18383	.16472	.39344	.29244
LFMB	.22405	.18353	.18387	.44220	.31888
XCB	.40689	.48976	.38742	.32168	.44920
NLB	.31600	.26160	.32747	.32274	.31908

	TSQH	PPL	QTPL	QTPH	TIND
MPD	.02435	-.01275	-.05634	-.08746	-.07053
LMPW	-.00083	-.03202	-.02006	-.08861	-.03444
MPL	-.04699	.00538	-.03092	-.04436	.01365
QGAP	.01595	-.02750	-.06516	.01090	.03081
QGML	-.00760	-.01419	-.05931	-.01250	-.05222
TSQH	.54222*	-.04466	-.01401	-.08453	-.01498
PPL	.43863	.62237*	-.02577	-.01295	-.02399
QTPL	.28676	.35328	.60922*	.02912	-.03875
QTPH	.37270	.31414	.28730	.50116*	.05547
TIND	.02911	-.05945	-.12969	-.05303	.63725*
QTTHK	.28920	.24962	.37006	.15717	-.41008
ATANGS	.08343	.13969	.10361	-.01799	-.37056
PANGS	.16597	-.28168	-.06754	.06970	.21658
PTANG	.10209	-.25544	-.12644	.14328	.07169
TANGS	.04784	.02475	.09647	-.11610	.14780
BANT	.06537	.23219	.12084	.11034	-.21520
MANG	-.09823	.05197	-.11523	-.04524	.13103
EANG	.18030	-.03759	-.24057	.08806	.09429
GOL	.53343	.49300	.48828	.31215	-.09197
AUB	.55411	.45917	.54655	.37176	.22208
BBH	.54147	.51548	.47088	.47316	-.19109
BANG	-.30488	-.21205	-.07687	-.42938	-.18653
FANG	-.05893	.06072	.01312	.11577	-.31305
LFML	.50250	.53234	.26954	.18240	-.03225
LFMB	.45269	.41090	.22357	.07137	.10757
XCB	.38454	.34167	.33640	.36787	.33232
NLB	.01644	.10995	.33276	.04059	-.04458

TABLE A.6.6 (Contd.)

	QTTHK	ATANGS	PANGS	PTANG	TANGS
MPD	-.01244	.02323	.05034	.05679	-.02326
LMPW	-.02144	.05069	.02767	.06660	-.06007
MPL	-.02475	.03092	.01676	.05046	-.04701
QGAP	.01978	-.00893	-.06818	-.06972	.01630
QGML	-.02110	.02229	-.04612	-.05234	.01915
TSQH	.04626	-.03561	-.04179	-.03431	-.00343
PPL	-.00988	-.03682	.10147	.07687	.01372
QTPL	-.02884	-.03523	-.00775	-.03086	.03259
QTPH	.06898	-.04631	-.02392	-.05361	.04609
TIND	.12697	.07438	-.03693	-.00719	-.03178
QTTHK	.68987*	-.12993	-.04802	-.05960	.02531
ATANGS	.45533	.60047*	.01089	.07360	-.08787
PANGS	.10311	-.01643	.89135*	.04136	.06634
PTANG	.03393	-.29091	.64637	.91529*	-.06549
TANGS	.07120	.37363	.13391	-.50662	.83638*
BANT	.22692	-.06907	-.25421	.22639	-.59376
MANG	-.31877	-.17512	-.04223	.07041	-.14508
EANG	-.20799	-.21820	.08605	.14651	-.10203
GOL	.54956	.22909	.05744	-.03381	.11071
AUB	.32731	.00907	.28162	.09563	.18931
BBH	.34758	.14677	.03524	-.00188	.04096
BANG	-.01080	.11795	-.16504	-.24278	.14345
FANG	-.10940	.08286	-.17666	-.11491	-.04608
LFML	.41953	.26969	.06415	-.03552	.11813
LFMB	.29287	.09136	.10013	.00064	.11125
XCB	.09298	-.06148	.24833	.10134	.14285
NLB	-.01511	-.21501	-.33072	-.21007	-.08678

	BANT	MANG	EANG	GOL	AUB
MPD	.09189	.12338	.03216	-.02996	-.03254
LMPW	-.04011	.01662	-.04842	.00145	-.01252
MPL	-.03047	.04057	-.05665	-.02903	-.00605
QGAP	.01624	.03023	.02891	-.02401	-.01650
QGML	.01169	-.02043	.07919	-.01477	-.03370
TSQH	.00303	.06397	-.05575	-.03864	.00782
PPL	-.05174	-.08115	-.03865	-.02550	.00479
QTPL	.02485	.02498	.15758	-.06059	.00761
QTPH	-.03662	.04186	.02154	-.02433	.02788
TIND	.06611	-.11443	-.03746	.02300	.05614
QTTHK	-.01953	.08004	.04374	-.03527	.02638
ATANGS	.05943	.07402	.07781	-.02253	.02621
PANGS	.07539	.00412	-.01221	-.01277	-.01894
PTANG	-.04755	-.01865	-.05706	.00605	-.01072
TANGS	.14539	.02841	.06031	-.02194	-.00748
BANT	.69327*	.01151	.13131	-.05229	.02464
MANG	.07786	.62539*	.14106	.01044	-.01976
EANG	-.22040	-.16309	.71517*	-.03927	.02621
GOL	.18754	-.31444	-.02462	.74894*	-.01489
AUB	.04794	-.07069	-.10250	.65972	.87470*
BBH	.05411	-.00060	.12130	.52495	.55057
BANG	-.13651	.04424	-.06845	-.21110	-.31642
FANG	-.09254	.36823	.03485	-.25728	-.22891
LFML	.19857	.00871	-.05238	.58598	.54323
LFMB	.09992	-.07298	.11085	.54150	.52692
XCB	.03998	.07638	-.18788	.38213	.66365
NLB	.03411	-.14140	.09676	.14790	.13523

TABLE A.6.6. (Contd.)

	BBH	BANG	FANG	LFML	LFMB
MPD	-.00722	.01975	.00247	.02782	-.00732
LMPW	-.00817	.12589	.05543	.03415	.05619
MPL	-.00520	.06759	.05518	.03247	.08282
QGAP	-.02289	-.08000	-.01271	-.04439	-.10040
QGML	-.04727	-.11467	-.01969	.00589	-.01667
TSQH	-.02318	.04575	-.07609	-.10798	-.13956
PPL	-.04763	.06186	-.01473	-.07286	-.05154
QTPL	-.06255	-.00477	-.07288	.00631	.03981
QTPH	-.11728	.14778	-.12470	.06104	.01738
TIND	.06330	.05083	.14524	-.01500	-.07230
QTTHK	-.03563	-.00034	.00553	-.04403	-.05744
ATANGS	.00087	.02298	-.01881	-.03200	.00432
PANGS	-.00493	-.00716	.00931	.02052	.01355
PTANG	.00078	.06756	.03561	.02532	.03540
TANGML	-.00625	-.10095	-.03783	-.00870	-.03214
BANT	.03289	-.04675	.03538	-.02944	-.05774
MANG	-.06937	-.01387	-.20857	-.04301	-.05548
EANG	-.08347	-.01425	-.10098	-.01832	-.09777
GOL	.04114	.00016	.02771	-.01871	-.05625
AUB	-.01040	.03886	.01360	-.03165	-.03874
BBH	.76073*	-.03652	-.00203	-.04579	.00805
BANG	-.20907	.57905*	-.01936	.00980	-.05390
FANG	.27176	.14065	.71026*	.04626	.08764
LFML	.46286	-.13416	-.11036	.71535*	-.04122
LFMB	.35985	-.03550	-.23799	.60912	.64867*
XCB	.32823	-.45838	-.18714	.34283	.25801
NLB	.17045	.15888	.02180	-.09616	.06049

	XCB	NLB
MPD	-.07904	-.06409
LMPW	-.00642	-.02379
MPL	-.02514	-.04574
QGAP	-.02149	-.12587
QGML	-.04950	-.09201
TSQH	-.03508	-.00919
PPL	-.00369	.04416
QTPL	.01089	-.10919
QTPH	-.03980	.03988
TIND	-.06428	.02618
QTTHK	-.03739	-.01142
ATANGS	.05780	.13725
PANGS	-.02909	.09616
PTANG	.01568	.04645
TANGS	-.05535	.04805
BANT	-.04428	.00990
MANG	-.07208	.00468
EANG	.05557	-.06836
GOL	.01745	.02327
AUB	-.02232	-.00206
BBH	.01501	.02392
BANG	.09151	-.09346
FANG	-.00043	-.01996
LFML	-.01793	.05151
LFMB	.01355	-.00627
XCB	.69380*	.07326
NLB	-.07019	.58285*

The lower left triangle contains the reproduced correlation matrix;
communalities are on the diagonal; residuals between the observed correlations and the reproduced correlations are in the upper right triangle,.

There are 110 (31.0%) residuals (above diagonal) that are > 0.05

TABLE A.8.1: *H.ERECTUS* SAMPLE

A sample of casts of fossils attributed to *H.erectus* from the Department of Human Origins, Natural History Museum, London.

CHINA	JAVA	JAVA (late)	AFRICA
Zhoukoudian	Sangiran	Ngandong	Olduvai
IIIE	2	1	OH9
V	4	6	OH12
X (L1)	10	7	East Turkana
XI (L2)	17	10	ER 3733
XII(L3)	Sambungmacan	11	ER 3883
	1	12	

TABLE A.8.2: AFRICAN APE SAMPLE

A sample of African (adult) apes from the Anthropology Department Napier Collection, University College London.

Gorilla gorilla	*Pan paniscus*
PA 1192 (male)	PA 1194
PA 1193 (male)	PA 1196
	PA 1197
PA 1282 (female)	PA 1198
	PA 1283*

* for 1 feature only, internal petrous transverse angle

TABLE A.8.3:
COMPARISON OF MODERN HUMANS, *H.ERECTUS* & APES:
TEMPORAL MEANS & STANDARD DEVIATION VALUES.

CRANIAL SAMPLE ABBREVIATIONS:

Hs = Modern *H.sapiens*, from 6 population groups;
KK = 2 Aust. modern *H.sapiens* fossils, Kanalda & Kow Swamp V;
Ng = Ngandong 1,6,7,10,11,12 *H.erectus* (casts);
JHe = Sangiran 2,4,10,17 & Sambungmacan 1 *H.erectus* (casts);
CHe = Zhoukoudian III.E, V.H, X.L1, XI.L2, XII.L3 *H.erectus* (casts);
AsHe = Asian *H.erectus:* Ng,JHe & CHe combined (casts);
AfHe = African *H.erectus:* OH9, OH12, ER-3733, ER-3883 (casts);
He = Asian & African *H.erectus* samples combined (casts);
Pan = *Pan paniscus*, (4);
Gor = *Gorilla*, (2 males, 1 female).

VARIABLE ABBREVIATIONS:

ATANG = Tympanic (Ant.Side) Sagittal Angle
BANG = Cranial Base Angle
BANT = Anterior Position of Basion
ENIN = Endinion-Inion Separation
FPOS = Posterior Position of F.Magnum
GFA = Glenoid Fossa Area
GFD = Glenoid Fossa Depth

TRAIT	Modern	Human	*H O M O*		*E R E C T U S*				A P E S	
	Hs	KK	Ng	JHe	CHe	AsHe	AfHe	He	Pan	Gor
ATANG										
Mean	79.90	79.00	91.42	86.63	95.50	91.21	85.83	90.26	74.00	75.50
SD	6.07	—	2.69	5.56	3.70	5.02	9.36	5.99	2.16	1.50
No.	328	1	6	4	4	14	3	17	4	3
BANG										
Mean	107.5	106.8	N.A.	123.7	N.A.	123.7	N.A.	123.7	131.9	141.5
SD	8.56	—		—		—		—	6.40	4.38
No.	328	1		1		1		1	4	3
BANT										
Mean	5.55	3.30	6.15	8.10	N.A.	7.13	N.A.	7.13	2.43	1.06
SD	2.33	—	2.33	.57		1.79		1.79	1.13	.60
No.	328	1	2	2		4		4	4	3
ENIN										
Mean	2.56	6.35	-20.8	-14.1	-26.7	-18.2	-9.60	-16.5	-14.5	-59.8
SD	5.6	5.4	5.4	2.4	—	5.8	1.98	6.3	1.96	15.4
No.	328	2	3	4	1	8	2	10	3	3
FPOS										
Mean	12.7	16.5	16.2	11.9	N.A.	14.0	N.A.	14.0	12.1	17.2
SD	2.6	—	.35	.49		2.5		2.5	1.1	1.2
No.	328	1	2	2		4		4	4	3
GFA	149.5					201.7				
Mean	23.1	167.6	243.0	200.4	162.1	46.6	244.3	211.5	176.5	395.7
SD	328	24.3	36.3	48.5	2.16	10	58.5	50.5	24.7	64.6
No.		2	3	4	3		3	13	4	3
GFD										
Mean	6.33	7.75	6.06	5.50	7.00	6.18	5.03	5.96	3.30	9.90
SD	1.09	.495	.899	1.77	.663	1.24	1.65	1.35	.883	.964
No.	328	2	5	4	4	13	3	16	4	3

TABLE A.8.3 COMPARISON OF MODERN HUMANS, *H.ERECTUS* & APES: TEMPORAL MEANS & STANDARD DEVIATION VALUES. (Contd.)

VARIABLE ABBREVIATIONS:

GFIDX = Glenoid Fossa Length/Width Ratio
GFV = Glenoid Fossa Volume
GOL = Cranial Length
MPD = Mastoid Process Transverse Depth
OCOOCA = Occipital Chord/Arc Ratio
OIX = Occipital/Nuchal Sag.Chord Ratio
PANG = Petrous Sagittal Angle
PPL = Petrous Pyramid Length
PTANG = Petrous-Tympanic Angle
SCANG = Suprameatal Crest Angle

TRAIT	Modern	Human	*H O M O*		*E*	*R E*	*C T*	*U S*	A P	E S
	Hs	KK	Ng	JHe	CHe	AsHe	AfHe	He	Pan	Gor
GFIDX										
Mean	72.58	68.30	75.71	71.75	78.78	75.44	66.05	73.68	48.88	48.68
SD	6.29	8.08	4.66	6.96	12.18	8.05	1.68	8.15	6.14	.614
No.	328	2	5	4	4	13	3	16	3	3
GFV										
Mean	13.70	15.65	14.46	14.03	14.22	14.25	14.40	14.28	10.78	21.39
SD	1.23	.590	1.51	2.03	.715	1.40	2.18	1.48	1.60	1.65
No.	328	2	5	4	4	13	3	16	3	3
GOL										
Mean	179.5	190.8	202.1	190.4	194.6	197.1	190.0	195.7	71.26	N.A.
SD	10.2	1.4	9.1	15.9	4.5	10.3	13.9	10.9	5.70	
No.	328	2	6	3	4	13	3	16	4	
MPD										
Mean	12.23	16.10	19.18	16.11	16.56	17.23	17.40	17.25	N.A.	11.85
SD	1.97	1.13	1.58	.965	1.36	1.83	.566	1.70		4.03
No.	327	2	4	4	5	13	2	15		3
OCCOCA										
Mean	84.20	85.79	73.30	74.22	74.82	74.05	73.27	73.90	83.50	N.A.
SD	3.00	2.84	3.12	5.15	1.69	3.32	3.53	3.25	2.03	
No.	328	2	5	4	4	13	3	16	4	
OIX										
Mean	180.8	189.5	152.6	124.0	126.5	137.0	124.0	134.7	71.26	N.A.
SD	29.3	39.0	19.9	19.3	21.8	23.4	12.5	22.1	5.70	
No.	328	2	6	4	4	14	3	17	4	
PANG										
Mean	45.61	45.50	37.50	39.50	41.00	39.00	37.50	38.44	26.13	24.67
SD	4.36	—	2.12	9.19	—	4.95	.500	3.83	1.93	.577
No.	328	1	2	2	1	5	3	8	4	3
PPL										
Mean	32.01	34.20	36.80	35.50	32.60	35.43	N.A.	35.43	30.78	40.23
SD	2.31	—	1.27	—	—	2.11		2.11	2.37	3.25
No.	328	1	2	1	1	4		4	4	3
PTANG										
Mean	162.5	158.5	157.0	152.5	151.5	153.7	150.0	152.4	139.1	136.7
SD	5.02	—	1.41	9.19	2.12	5.01	6.38	5.41	3.42	3.69
No.	327	1	2	2	2	6	3	9	4	3
SCANG										
Mean	12.26	10.25	12.90	20.50	20.40	18.09	22.83	18.84	43.50	40.83
SD	5.35	1.77	3.93	3.77	.962	4.71	7.01	5.20	7.05	13.2
No.	328	2	5	6	5	16	3	19	4	3

TABLE A.8.3 COMPARISON OF MODERN HUMANS, *H.ERECTUS* & APES: TEMPORAL MEANS & STANDARD DEVIATION VALUES.(Contd.):

VARIABLE ABBREVIATIONS:

SMCGOL = Cranial Breadth/Length Ratio
SMCXCB = Lower/Upper Cranial Breadth Ratio
TANG = Tympanic Axis Sagittal Angle
TIND = Tympanic Rim Indent
TTHK = Tympanic Rim Thickness
TSQH = Temporal Squamous Height
TPL = Tympanic Plate Length
IPANGT = Int.Petrous Transverse Angle.

TRAIT	Modern Human		*H O M O*		*E*	*R E C T*		*U S*	A P	E S
	Hs	KK	Ng	JHe	CHe	AsHe	AfHe	He	Pan	Gor
SMCGOL										
Mean	72.36	70.65	75.89	77.76	76.02	76.36	75.18	76.14	87.39	86.33
SD	3.45	6.27	3.84	3.13	1.15	2.96	2.50	2.84	1.82	2.07
No.	328	2	6	3	4	13	3	16	4	3
SCXCB										
Mean	96.29	96.25	105.2	106.2	108.0	106.3	109.9	106.8	116.5	125.7
SD	3.99	6.01	2.78	3.00	3.77	3.11	1.91	3.20	2.65	6.81
No.	328	2	6	6	4	16	3	19	4	3
TANG										
Mean	63.04	67.00	64.25	66.25	70.67	66.35	67.50	66.56	67.00	68.00
SD	3.80	—	3.37	3.77	2.52	4.03	6.73	4.39	2.12	3.12
No.	328	1	6	4	3	13	3	16	4	3
TIND										
Mean	7.352	4.450	9.633	8.500	9.375	9.236	6.633	8.777	4.275	1.267
SD	1.60	1.77	2.60	3.84	2.29	2.73	2.32	2.79	1.57	1.07
No.	328	2	6	4	4	14	3	17	4	3
TTHK										
Mean	2.853	2.725	4.370	3.763	4.260	4.157	2.500	3.865	1.663	2.717
SD	1.29	.955	.497	.914	.658	.687	.200	.901	.180	1.09
No.	328	2	5	4	5	14	3	17	4	3
TPL										
Mean	26.87	31.40	31.24	33.38	28.14	30.74	N.A.	30.74	34.38	51.50
SD	2.60	1.84	3.61	6.55	2.43	4.53		4.53	2.16	5.12
No.	328	2	5	4	5	14		14	4	3
TSQH										
Mean	45.52	44.25	40.70	41.05	40.84	40.85	38.20	40.38	21.35	28.10
SD	5.10	2.47	.975	7.12	2.82	3.80	2.55	3.69	2.20	2.61
No.	327	2	5	4	5	14	3	17	4	3
IPANGT										
Mean	77.7	N.A.	N.A.	101.5	N.A.	101.5	104.0	102.8	N.A.	109.0
SD	4.23			—		—	—	1.77		17.0
No.	15			1		1	1	2		2

TEMPORAL BONE VARIATION IN AUSTRALIAN ABORIGINES AND OTHER MODERN POPULATIONS: IMPLICATIONS FOR THE ORIGIN OF MODERN HUMANS

SUPPLEMENT

3.3 THE EVOLUTION OF THE TEMPORAL BONE IN HOMINIDS

Dissertation submitted

by Rob Mary Robinson

for the degree of Doctor of Philosophy

University College London

June 1995

3:3 THE EVOLUTION OF THE TEMPORAL BONE IN HOMINIDS

3.3.1 MASTOID MORPHOLOGY

In evaluating cranial morphological changes in the course of hominid evolution, the literature concentrates on general cranial features. However, several aspects of the temporal bone, if not consistently considered for all hominid groups, have been emphasised as distinguishing features of particular hominid groups in relation to one or more other groups.

Considerable variation in mastoid dimensions exists within all hominid groups, but the overall size can be described as large and inferiorly projecting in modern *H.sapiens*, large and laterally projecting in *A.boisei* and *A.robustus*, and comparatively small in Neanderthals, Archaic *H.sapiens*, early *Homo* (including *H.habilis*, and *H.sp.indet.*), *A.africanus* and *A.afarensis*. The Neanderthal mastoid may sometimes appear to be deceptively small because of the proximity of a large juxtamastoid eminence. (Aiello & Dean 1990:229; Clarke 1990:714; Howells 1993:136; Klein 1989:272; Suzuki 1970:146; Tobias 1967:28,195; 1991:92,93,766; Trinkhaus 1983:68,69; Walensky 1964:67-70; Weidenreich 1943:22,62-64, 205; 1951:279; White et al.1981:457; Wood 1991:74,99,272).

In great apes, also, there is considerable variation in the degree and form of mastoid development; very occasionally, the ape mastoid can develop late in the ape, even becoming as large as that of modern *H.sapiens*. Nevertheless, the usual great ape/Miocene hominoid morphology of a small to negligible mastoid process with extreme inflexion (medial bending) and extensive pneumatization throughout the mastoid region is regarded as the primitive mastoid morphology. (Aiello & Dean 1990:229; Kimbel et al.1985:122; Olson 1985:104; Tobias 1967: 28; Weidenreich 1943:62,64,205;1951:279). Of all hominids, *A.afarensis* shares this primitive morphology, showing greater resemblance than other australopithecines; in fact, *A.afarensis* is regarded as distinguishable from other australopithecines on the basis of its mastoid features, especially in its marked medial mastoid inflexion. At the opposite extreme, modern *H. sapiens* crania have the most vertical mastoid process. (Kimbel

et al.1984:337,374,377-380; Tobias 1967:195; White et al. 1981:455-6; Wood 1991:21; contra Olson 1985:107,114).

Pneumatization in the ape temporal bone is very great, commonly occurring not just in the mastoid but in the whole temporal squama as well. Though not as extreme as in apes, pneumatization in the australopithecine mastoid region is considerable, extending at least partly into the temporal squama in *A.afarensis* (e.g. Hadar 333-45) and *A.boisei* (e.g. OH5). Lateral inflation of the mastoid region is found in all australopithecines, especially *A.boisei* and *A.robustus*. By contrast, pneumatization is less in the mastoid region of early *Homo*, and comparatively reduced in the mastoid region of all subsequent *Homo* groups, including *H.erectus*. (Kimbel et al.1984:379; 1985:120-123; Tobias 1967:212; 1991:93,761,766; Wood 1991:21,51,52,56,66,74,105).

If extensive pneumatization accounts for the very large, laterally projecting mastoids of robust australopithecines, the opposite tendency of reduced pneumatization explains the prominence of the modern *H.sapiens* mastoid. It is precisely the restriction of pneumatization to the mastoid process in the modern *H.sapiens* temporal region which contributes to its increased verticality, cone-shaped inferior projection and deep digastric fossa (White et al.1981:457; Wood 1991:63,264).

The underlying functional significance of a prominent mastoid process may also be quite different for modern *H.sapiens* and robust australopithecines. Sternocleidomastoid muscles attach to the mastoid process and control various head movements. In relation to the axis of rotation of the occipital condyles, the positioning of the mastoid process (and hence of the sternocleidomastoid muscles) differs in modern *H.sapiens* compared to early hominids and apes. It means that the sternocleidomastoid muscles in modern *H.sapiens*, while still important in rotating the head from left to right, are less important in contributing support in relation to the weight of the face (as is the case in apes, robust australopithecines and other early hominids), and are principally concerned with returning the head to the horizontal position after it has become imbalanced backwards. (Aiello & Dean 1990:229,230; Krantz 1963:591-3).

Mastoid morphology was also proposed as a means of distinguishing between the robust australopithecines and

A.africanus, on the basis of the more laterally inflated mastoid process of the former and the well defined occipitomastoid and juxtamastoid crests in the latter. However, this was shown to be unreliable criteria given the variability in the mastoid morphology of both groups (e.g. MLD37/38 (*A.africanus*) has laterally inflated mastoid; KNM-ER732 (*A.boisei*) has an occipitomastoid crest). (Kimbel et al. 1985:120-123; Olson 1985:102,112; Wood 1991:60,69).

The juxtamastoid crest or eminence is considered to be an important diagnostic feature of Neanderthals. Certainly, the structure is seen in most Neanderthals, particularly those regarded as "Classic Neanderthals", as a strikingly prominent feature, sometimes being even larger than the mastoid process. However, there is doubt that a juxtamastoid crest can be regarded as an autapomorphic trait of Neanderthals since it is not evident in every Neanderthal cranium and it does occur, albeit less frequently and less prominently, in *H.sapiens*, early *Homo*, *A.africanus* and more rarely in *H.erectus* and robust australopithecines. Also, some confusion appears to exist in distinguishing between juxtamastoid and occipitomastoid crests. McKee and Helman (1991:275,280) concluded that the juxtamastoid crest is too variable and prone to misinterpretation and observer error to be a reliable phylogenetic or taxanomic indicator. It has been suggested that crania with small mastoid processes (e.g. *A.africanus* and early *Homo*) needed the juxtamastoid eminence to increase the area for muscle attachment. (Aiello & Dean 1990:229; Howells 1993:136; Hublin 1988:81; Kimbel et al.1985:126-128; Klein 1989:272; Olson 1985:105,108; Suzuki 1970:146; Trinkhaus 1983:68,69; 1988:13-16,23; Walensky 1964:677,69,70); Wood 1991:37,51,52,60,69,81,90,91,105,106).

The mastoid fissure (broad gap between the tympanic petrosal crest and the anterior surface of the mastoid) was proposed as a uniquely derived feature of Asian *H.erectus*. Brauer & Mbua (1992:91,100) examined crania from a wide selection of hominid groups, *A.africanus*, early *Homo*, *H.erectus* and Archaic *H.sapiens*, and found that the mastoid fissure is present in some representatives of all the hominid groups but that within every group it shows great variability in occurrence and form. Tobias (1991:94,766) found the mastoid

fissure present in early *Homo* (e.g.OH24 (*H.habilis*)) and other gracile early hominids (e.g. MLD 37/38 (*A.africanus*)) and observed that a heavily inflated mastoid appears to obliterate the mastoid groove (e.g.OH5 (*A.boisei*)).

Prominent mastoid and supramastoid crests are associated with *H.erectus*, particularly in the Asian specimens. Prominent mastoid crests continuous with the nuchal crest have also been noted in *A.boisei*. Strong supramastoid crests, continuous with the temporal line posteriorly and with the zygomatic process anteriorly, have been observed in *A.boisei*, early *Homo*, Neanderthals and modern *H.sapiens*. (Bilsborough 1992:190; Klein 1989:272; Trinkhaus 1983:69; Tobias 1967:28; 1991:93,772; Weidenreich 1943:63,201,205; Wood 1991:59).

3.3.2 TYMPANIC MORPHOLOGY

A reduction in the length of the tympanic plate occurs from pongids to australopithecines to *Homo*. The tympanic plate length, together with the overall cranial breadth, may relate to the degree of development of the masticatory system, a reduction in all 3 features occurring in the later hominids (Aiello & Dean 1990:227,228). In general, the tympanic plate of modern *H.sapiens* is shorter than that of Neanderthals or *H.erectus*, although all 3 are considerably shorter than the ape tympanic plate (Tobias 1991:95,766; Trinkhaus 1983:134; Weidenreich 1943:54).

In basal view, the tympanic plate is aligned coronally in African apes, australopithecines, early *Homo* and *H.erectus*. It is more sagitally inclined in modern *H.sapiens* and Neanderthals, possibly corresponding to the reduction in tympanic plate length; e.g. the tympanic axis of most modern *H.sapiens* crania lie between 50-80° to the sagittal plane. (Kimbel & White 1988:186; Trinkhaus 1983:70,134; Weidenreich 1943:52,202; 1951:278,279; Wood 1991:91,100,105).

The tympanic plate in apes is orientated horizontally, with anterior/posterior margins. This primitive aspect of tympanic morphology is shared with *A.afarensis*, later hominids having the derived condition of a more vertically inclined tympanic plate with inferior/superior margins and the inferior margin forming a petrosal crest. The orientation in *A.africanus* is seen by some as an intermediate condition.

Modern *H.sapiens* is reported to be the hominid group with the most vertically orientated tympanic plate. The *A.boisei* tympanic plate is also particularly vertical, being closer to the modern *H.sapiens* condition than that of *H.erectus*, which in turn is more vertical than Neanderthal. (Aiello & Dean 1990: 102; Kimbel & White 1988:186; Kimbel et al.1984:375,376; Tobias 1967:30,195; 1991:95; Weidenreich 1943:48,52,59,202; 1951:274-7; White 1988:513; White et al.1981:456; Wood 1991:52,100,264).

The primitive shape of the tympanic inferior surface, as seen in apes and *A.afarensis*, is tubular (convex). This also best describes the condition which tends to occur in early *Homo* and *H.erectus*. In other australopithecines and later *Homo*, the tympanic plate is usually concave, continuous with the curvature of the glenoid fossa and forms its posterior wall. (Brown et al. 1993:146; Kimbel et al.1984:374; Kimbel & White 1988:186; Tobias 1967:30,196;1991:95,765; Trinkhaus 1983:134; Weidenreich 1943: 54,202; 1951:275; White et al.1981:456; Wood 1991:21,81,264).

The rim of the tympanic plate in hominids is overshadowed to varying degrees by the posterior root of the zygoma / suprameatal crest. In *H.erectus* the overhang is of striking depth, largely because of the prominence of the zygomatic root. In African apes there is little or no overhang and in some *Gorilla* crania the tympanic may even extend more laterally than auriculare. (Tobias 1967:30,195,199; 1991: 95,766; Weidenreich 1943:22,53,202; 1951:275).

In some hominids the tympanic plate ends medially in a supratubalis process, a particularly large, robust and pointed structure in apes. Among hominids, the supratubalis has been recorded as most prominent, though to less degree than in apes, in representatives of *A.africanus*, *A.robustus*, early *Homo* and *H.erectus*. The process occurs in modern *H.sapiens* but is variable in size and shape. Since it tends to be weak or completely absent in *A.boisei*, the feature may be a means of distinguishing between the 2 robust australopithecine species. (Rightmire 1990:189;Tobias 1991:94,765;Weidenreich 1943:61,204).

A general thinning of the tympanic plate occurred in the course of hominid evolution, but the lateral rim was least affected. The anthropoid tympanic is thicker than that of most hominid groups with 2 exceptions, *H.erectus* and Neanderthals. Very thick rims can occur in some modern *H. sapiens*

populations, but early *Homo* crania tend to have thicker tympanic plates than Archaic or recent modern *H.sapiens*. (Rightmire 1990:236; Tobias 1967:30-32,196; 1991:96; Weidenreich 1943:54,203;1951:275; Wood 1991:141). The thickest part of the tympanic rim in early *Homo* and modern *H.sapiens* is the most inferior section, whereas in *A.boisei* the thickest section is more posteriorly situated, the floor being the thinnest (Brown et.al.1993:146; Tobias 1991:30-32,96,196).

3.3.3 STYLOID PROCESS

An ossified styloid process is a feature which occurs with varying degrees of prominence in modern *H.sapiens* crania and has also been found present in Neanderthals and some Archaic *H.sapiens* (e.g. Ndutu, Sale). The styloid process is generally considered to be absent in apes, all australopithecines, *H.erectus* and early *Homo*, but a few exceptions have been noted (e.g. early *Homo*, SK847 and African *H.erectus*, KNM-ER 3733). (Clarke 1990:711,721-2; Tobias 1967:3, 196;1991:91; Weidenreich 1943:28,60; Wood 1991:33,37,52,105).

The vaginal process in modern *H.sapiens* appears as a curving modification in the tympanic plate to accommodate and possibly protect the styloid process. But, it is also present in the crania of some hominid groups (*H.erectus*, early *Homo*, and *A.boisei*) in which the styloid process does not appear to develop. (Brown et al.1993:146; Kimbel & White 1988:186-7; Tobias 1967:33,196;1991:94; White 1988:513; Wood 1991:52,59,91,100).

3.3.4 PETROUS MORPHOLOGY

A.afarensis shares the primitive condition seen in pongids of a sagitally inclined petrous pyramid and acute angle between the petrous pyramid and tympanic plate. Modern *H.sapiens* departs most from this in having the most coronally aligned petrous pyramid and largest petrous-tympanic angle of all hominids. The petrous angles recorded for *A.africanus* are greater than those associated with the primitive condition but notably more acute than those of robust australopithecines and all *Homo*. (Dean 1988:108,110; Kimbel & White 1988:186; Tobias 1967:197; 1988:296,301,304; 1991:97,767; Weidenreich 1943:57, 58,60,204;1951:278; Wood 1991:52,60,67,74,82,91,264,272,278).

There are diverse interpretations of the *A.africanus*

petrous morphology. Wood (1991:60,264) considered the petrous orientation of *A.africanus* to be so sagittal relative to that of *A.robustus* and *A.boisei* that it can be regarded as a primitive retained feature distinguishing *A.africanus* from robust australopithecines. White (1988:514) concluded that this discounted *A.africanus* as the most recent common ancestor of robust australopithecines and *Homo*. Tobias (1988:299,301; 1991:100), however, saw the petrous orientation in *A.africanus* as transitional between pongids and other hominids (robust australopithecines and *Homo*); he discounted *A.afarensis*, with its sagitally aligned petrous, as the most recent common ancestor of robust australopithecines and *Homo*, and suggested a more likely contender would be a later, as yet unknown *A.africanus* with a more coronal petrous.

The striking difference in the petrous angles of robust compared to gracile australopithecines has prompted the suggestion of a connection between petrous orientation and mastication (White 1988:513,524).

As a derived feature shared by *A.boisei*, *A.robustus*, and *Homo*, increased coronal orientation has been seen as related to one or more of the following developments: increased orthognathism, increased cranial base flexion, reduced cranial base (basio-occipital) length, anteriority of the foramen magnum and cerebellar expansion. However, opinions differ as to which features are more important and perhaps causal.

(i) According to Kimbel et al.(1984:375,377), the petrous becomes more coronally orientated as the cranial base becomes more flexed, which in turn is related to mid-facial orthognathism. Since orthognathism is a consequence in *Homo* but not in robust australopithecines of reduced masticatory apparatus, orthognathism and hence coronal petrous orientation is a parallel development in the 2 groups.

(ii) Tobias (1967:197,272,278; 1951:97) emphasises that increased orthognathism and coronal petrous orientation are consequences of reduced cranial base length.

(iii) Weidenreich (1943:58) relates increased coronal petrous alignment and reduced cranial base length to "rolling up" of the brain case about a transverse axis through porion.

(iv) Dean (1988:108,110) holds that the relatively coronal orientation of the petrous pyramid in *H.sapiens* and robust

australopithecines corresponds to their shortened, more flexed cranial bases; but he proposes that to understand the increased coronal petrous orientation from pongids to modern *H.sapiens*, cerebellar expansion must also be considered. Differences in petrous orientation between apes and humans exist at birth. During foetal development in modern *H.sapiens* the cerebellum expands faster than the cranial base lengthens, resulting in lateral brain and base expansion and more coronal orientation of the petrous, together with a more anteriorly positioned foramen magnum. In great apes, the relatively faster growing cranial base permits the cerebellum to expand posteriorly and, compared to hominids, a more sagitally inclined petrous and posteriorly placed foramen magnum result.

The combined effect of cerebellar expansion and cranial base shortening as proposed by Dean, equally well explains some endocranial aspects of hominid petrous morphology. From apes to modern *H.sapiens*, the petrous bone increases in height, the posterior wall changes from gradually sloping to approximately vertical, and the superior and posterior surfaces meet at a more acute angle, forming an increasingly sharp edge. In these features, robust australopithecines are more similar to *Homo* than to *A.africanus;* in fact, they are more similar to modern *H.sapiens* than are early *Homo* or *H.erectus*. A petrous feature characteristic of modern *H.sapiens* and observed also in Neanderthal, Archaic *H.sapiens*, early *Homo*, and *A.boisei,* but not in *H.erectus*, is that the superior surface overhangs the posterior surface largely because of a prominent sigmoid sulcus in the posterior petrous wall. (Brown et al.1993:146; Clarke 1990:717,722; Dean 1988:108-110; Suzuki 1970:150-1; Tobias 1967:57,201;1991:132-3,136,767; Weidenreich 1943:67-8,206;1951:286; Wood 1991:67,74-5,91,261,264).

3.3.5 GLENOID FOSSA MORPHOLOGY

The primitive morphology of the glenoid fossa as seen in apes and *A.afarensis* is a wide, shallow structure with a low weakly inclined articular eminence, a massive, inferiorly projecting entoglenoid process and a large postglenoid process. The glenoid fossa of *A.africanus* is highly variable but it is usually wide, quite shallow and has a more pronounced articular eminence than that of *A. afarensis*. In

A.africanus, approximately 1/3 of the fossa width lies lateral to the cranial vault wall. In *A.robustus* and *A.boisei*, the glenoid fossa is so wide that up to 2/3 lies lateral to the cranial vault wall. While much larger overall and deeper than that of *A.africanus*, the robust australopithecine glenoid fossa has shortened anteriorly/posteriorly; the articular eminence and tubercle have become more prominent, and the postglenoid process is variously recorded as small to large. In robust australopithecines the roof of the glenoid fossa is higher than the Frankfurt Horizontal, contrasting with *A.africanus* where it is well below.

In early *Homo* the width of the glenoid fossa decreases, only 1/5 lying lateral to the cranial vault wall. In *H.erectus* the postglenoid process is greatly reduced; there is a shortening of the fossa anteriorly/posteriorly, though it is wide and deep, more so than in the average modern *H.sapiens* or Neanderthal cranium. Archaic *H.sapiens* generally have a deep, short fossa with small postglenoid process and clearly defined articular eminence. The Neanderthal glenoid fossa is variable but generally wide and shallow, with a prominent postglenoid process which usually forms a large part of the posterior wall. However, Trinkhaus (1988:14) cautions that the shape evident in some adult Neanderthal crania may be due to remodelling caused by dental occlusion, attrition etc. Certainly, dimensions of the glenoid fossa in modern *H.sapiens* are known to be affected by age, attrition and tooth loss.

Robust australopithecines and *Homo* share the derived features of a deeper glenoid fossa and a steep, strong articular eminence. From apes to modern *H.sapiens*, the tympanic plate becomes more important and the postglenoid process less so in forming the glenoid fossa posterior wall. The entoglenoid process alters in the course of hominid evolution from the smooth, massive process seen in apes and composed entirely of temporal squama to a smaller structure in *Homo*, consisting of sphenoid as well as temporal bone and, at least in *H.sapiens*, usually incorporating a sphenoid spine. However, there is diversity in the entoglenoid process; a mixed temporal/sphenoid composition has been observed in *A. africanus*, while in African *H.erectus* the process is reported as large, smooth and composed entirely of temporal bone. In

this feature, *A.africanus* and early *Homo* are closer to the modern *H.sapiens* pattern than are *A.robustus* and *A.boisei*. (Brown et al.1993:146; Aiello & Dean 1990:103-5; Clarke 1990: 728,771; Dean 1988:108-110; Kimbel et al.1984:375; Kimbel & White 1988;186; Suzuki 1970:150-1; Tobias 1967:37,40-1,57,197-8,201 259;1991:101,104-9,132-3,136,763-4,767; Trinkhaus 1988:14,23; Weidenreich 1943:22,27-8,45,47-8,51,201-2;1951:271,273-4; Wood 1991:20-1,53,59-63,68,70,74-76,83,85,91-3,100,105,264,278).

Between the tympanic plate and the entoglenoid medial wall of the glenoid fossa in *H.erectus* there commonly occurs a medial recess. The presence of a fissure or cleft which arguably corresponds to this medial recess has been observed also in a wide range of other hominids including *A.africanus*, early *Homo* and Archaic *H.sapiens* (Brauer & Mbua 1992:102-105; Kennedy 1991:400; Rightmire 1990:189; Tobias 1991:109,110,764; Weidenreich 1943:47).

3.3.6 TEMPORAL SQUAMOUS MORPHOLOGY

In modern *H.sapiens* and Neanderthals, the temporal squamous is high, the superior margin being curved. The temporal squamous of *H.erectus* is ape-like, being low and with a flat superior border; it has been described as triangular with a right angle between the parietal and sphenoid borders. Early *Homo* and *A.boisei* also have low temporal squama. (Suzuki 1970:145,199; Tobias 1967:63,203; 1991:257; Weidenreich 1943:21,43,200; 1951:269; Wood 1991:90,104).

3.3.7 EXTERNAL AUDITORY MEATUS

No simple trend in the shape, size and orientation of the hominid auditory meatus from the ape condition through to that of modern *H.sapiens* can be deduced from accounts in the literature, but the following variations have been reported:- *Gorilla* and *Pan:* small and round; *A.boisei*: large, elliptical, sloping infero-posteriorly; early *Homo*: elliptical, sloping infero-anteriorly; *H.erectus*: large, variable shape and orientation; Neanderthals: elliptical, horizontal, lying above the roof of the glenoid fossa in the same horizontal plane as the zygomatic process; modern *H.sapiens:* elliptical, sloping infero-posteriorly. (Brown et al.1993:146; Condemi 1988:41; Hublin 1988:81; Tobias 1967:32,33,196;1991:96,97; Trinkhaus 1988:14,15; Weidenreich 1943:55,56,203; Wood 1991:52).

3.3.8 SUMMARY

The development of temporal bone morphology in hominid evolution proceeds from a primitive ape-like condition in *A.afarensis* with its heavily pneumatized temporal region to the modern *H.sapiens* situation in which temporal pneumatization is greatly reduced. Other trends accompanying this change in pneumatization include an increase in mastoid process prominence, the trend being from a lateral inflation and a small, medially inclined process in *A.afarensis* to the prominent mastoid process of modern *H.sapiens* which projects inferiorly and vertically rather than bending medially.

In the pattern of change in the tympanic from *A.afarensis* to *H.sapiens*, the tympanic plate becomes shorter, medially thinner and concave rather than convex, more vertically orientated and its axis somewhat less coronally inclined. Externally, the petrous pyramid shows a marked change from the ape-like condition in *A.afarensis* of an acute sagittal orientation to a considerably more coronal orientation in modern *H.sapiens*. Endocranially, the petrous posterior wall becomes more vertical, meets the superior surface at a more acute angle and forms a sharp rather than rounded superior/posterior edge.

The primitive hominid glenoid fossa morphology as seen in *A.afarensis* is of a very wide and shallow structure with weak articular eminence and massive postglenoid and entoglenoid processes, the latter being composed entirely of temporal squamous bone. In modern *H.sapiens*, the glenoid fossa has narrowed and deepened, the articular eminence is prominent, well-defined and sharply angled and the postglenoid process is much smaller. The entoglenoid process is also less prominent, composed of sphenoid as well as temporal bone and usually involves a sphenoid spine.

A.robustus and *A.boisei* show greater similarity to modern *H.sapiens* than to other australopithecines in a few features such as petrous and tympanic orientation and glenoid fossa shape. Rather than indicating phylogenetic or taxonomic affinity, these appear to be parallel developments related to other features (e.g.cranial base length and flexion and facial orthognathism), implying that the underlying causes in modern *H.sapiens* are different to those in robust australopithecines.

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